

**Collision of Union Pacific Railroad Train
MHOTU-23 With BNSF Railway Company
Train MEAP-TUL-126-D With Subsequent
Derailment and Hazardous Materials Release
Macdona, Texas
June 28, 2004**



Railroad Accident Report

NTSB/RAR-06/03

PB2006-916303

Notation 7675D



**National
Transportation
Safety Board**

Washington, D.C.

Railroad Accident Report

**Collision of Union Pacific Railroad Train
MHOTU-23 With BNSF Railway Company
Train MEAP-TUL-126-D With Subsequent
Derailment and Hazardous Materials Release
Macdona, Texas
June 28, 2004**

**NTSB/RAR-06/03
PB2006-916303
Notation 7675D
Adopted July 6, 2006**



**National Transportation Safety Board
490 L'Enfant Plaza, S.W.
Washington, D.C. 20594**

National Transportation Safety Board. 2006. *Collision of Union Pacific Railroad Train MHOTU-23 With BNSF Railway Company Train MEAP-TUL-126-D With Subsequent Derailment and Hazardous Materials Release, Macdona, Texas, June 28, 2004. Railroad Accident Report NTSB/RAR-06/03.* Washington, DC.

Abstract: About 5:03 a.m., central daylight time, on Monday, June 28, 2004, a westbound Union Pacific Railroad (UP) freight train traveling on the same main line track as an eastbound BNSF Railway Company (BNSF) freight train struck the midpoint of the 123-car BNSF train as the eastbound train was leaving the main line to enter a parallel siding. The accident occurred at the west end of the rail siding at Macdona, Texas, on the UP's San Antonio Service Unit. The collision derailed the 4 locomotive units and the first 19 cars of the UP train as well as 17 cars of the BNSF train. As a result of the derailment and pileup of railcars, the 16th car of the UP train, a pressure tank car loaded with liquefied chlorine, was punctured. Chlorine escaping from the punctured car immediately vaporized into a cloud of chlorine gas that engulfed the accident area to a radius of at least 700 feet before drifting away from the site. Three persons, including the conductor of the UP train and two local residents, died as a result of chlorine gas inhalation. The UP train engineer, 23 civilians, and 6 emergency responders were treated for respiratory distress or other injuries related to the collision and derailment. Damages to rolling stock, track, and signal equipment were estimated at \$5.7 million, with environmental cleanup costs estimated at \$150,000.

The safety issues discussed in this report are train crew fatigue and the vulnerability, under current operating practices, of railroad tank cars carrying hazardous materials.

As a result of its investigation, the National Transportation Safety Board makes safety recommendations to the Federal Railroad Administration, the Union Pacific Railroad, the Brotherhood of Locomotive Engineers and Trainmen, and the United Transportation Union. In addition, the Safety Board reiterates six safety recommendations previously issued to the Federal Railroad Administration.

The National Transportation Safety Board is an independent Federal agency dedicated to promoting aviation, railroad, highway, marine, pipeline, and hazardous materials safety. Established in 1967, the agency is mandated by Congress through the Independent Safety Board Act of 1974 to investigate transportation accidents, determine the probable causes of the accidents, issue safety recommendations, study transportation safety issues, and evaluate the safety effectiveness of government agencies involved in transportation. The Safety Board makes public its actions and decisions through accident reports, safety studies, special investigation reports, safety recommendations, and statistical reviews.

Recent publications are available in their entirety on the Web at <<http://www.nts.gov>>. Other information about available publications also may be obtained from the Web site or by contacting:

**National Transportation Safety Board
Records Management Division, CIO-40
490 L'Enfant Plaza, S.W.
Washington, D.C. 20594
(800) 877-6799 or (202) 314-6551**

Safety Board publications may be purchased, by individual copy or by subscription, from the National Technical Information Service. To purchase this publication, order report number **PB2006-916303** from:

**National Technical Information Service
5285 Port Royal Road
Springfield, Virginia 22161
(800) 553-6847 or (703) 605-6000**

The Independent Safety Board Act, as codified at 49 U.S.C. Section 1154(b), precludes the admission into evidence or use of Board reports related to an incident or accident in a civil action for damages resulting from a matter mentioned in the report.

Contents

Acronyms and Abbreviations	v
Executive Summary	vi
Factual Information	1
Accident Synopsis	1
Events Preceding the Accident	2
BNSF Train MEAP-TUL-126-D	2
UP Train MHOTU-23	2
The Accident Trip	3
The Accident	5
Emergency Response	8
Injuries	10
Damages	11
UP Lead Locomotive	11
Tank Car Damages	11
Flatcar Damages	12
Monetary Damages	12
Personnel Information	14
The UP Engineer	14
The UP Conductor	14
The UP Crew's Work Schedule and Activities Before the Accident	15
Toxicological Information	18
Meteorological Information	19
Site Description	20
The Railroad	20
The Community	20
Tank Car Information	21
Hazardous Materials Information	21
Tests and Research	22
Sight-Distance Tests	22
Tank Car Examination	22
Signal Inspection	23
Track Inspection	24
Mechanical Testing	25
Operating Rules and Crew Responsibilities	25
Delayed Release of UP Crews After Maximum Hours of Service	26
UP Fatigue Management	28
Fatigue Awareness Program	28
Fatigue Training for the UP Crew	31
Other Information	31
UP Drug and Alcohol Testing Program	31
FRA Oversight of the UP	32
Postaccident Actions of the UP	32
Postaccident Actions of Emergency Response Agencies	34

Analysis	36
General	36
The Accident	36
Exclusions	37
UP Train Crew Work, Rest, and Fatigue	38
UP Engineer's Activities and Rest	38
UP Conductor's Activities and Rest	40
UP Crew Performance During the Accident Trip	41
The Engineer's Performance	42
The Conductor's Performance	43
Emergency Response	44
Tank Car Performance	45
Previous Safety Board Actions Regarding Tank Cars	47
Minot	47
Graniteville	53
Work Schedules and Limbo Time	53
Positive Train Control	55
Train Crew Protection From Inhalation Hazards	56
Conclusions	58
Findings	58
Probable Cause	59
Recommendations	60
New Recommendations	60
Recommendations Reiterated in This Report	61
Recommendations Reclassified in This Report	62
Appendix A: Investigation	65

Acronyms and Abbreviations

AAR	Association of American Railroads
BLET	Brotherhood of Locomotive Engineers and Trainmen
BNSF	BNSF Railway Company
CFR	<i>Code of Federal Regulations</i>
CRZ	Cab Red Zone
DOT	U.S. Department of Transportation
EOT	end-of-train telemetry device
FRA	Federal Railroad Administration
IDLH	immediately dangerous to life and health
MP	milepost
NIST	National Institute of Standards and Technology
PTC	positive train control
Southwest	Southwest Research Institute
TDD	train defect detector
UMLER	Universal Machine Language Equipment Register
UP	Union Pacific Railroad
UTU	United Transportation Union

Executive Summary

About 5:03 a.m., central daylight time, on Monday, June 28, 2004, a westbound Union Pacific Railroad (UP) freight train traveling on the same main line track as an eastbound BNSF Railway Company (BNSF) freight train struck the midpoint of the 123-car BNSF train as the eastbound train was leaving the main line to enter a parallel siding. The accident occurred at the west end of the rail siding at Macdona, Texas, on the UP's San Antonio Service Unit. The collision derailed the 4 locomotive units and the first 19 cars of the UP train as well as 17 cars of the BNSF train. As a result of the derailment and pileup of railcars, the 16th car of the UP train, a pressure tank car loaded with liquefied chlorine, was punctured. Chlorine escaping from the punctured car immediately vaporized into a cloud of chlorine gas that engulfed the accident area to a radius of at least 700 feet before drifting away from the site. Three persons, including the conductor of the UP train and two local residents, died as a result of chlorine gas inhalation. The UP train engineer, 23 civilians, and 6 emergency responders were treated for respiratory distress or other injuries related to the collision and derailment. Damages to rolling stock, track, and signal equipment were estimated at \$5.7 million, with environmental cleanup costs estimated at \$150,000.

The National Transportation Safety Board determines that the probable cause of the June 28, 2004, collision of Union Pacific Railroad train MHOTU-23 with BNSF Railway Company train MEAP-TUL-126-D at Macdona, Texas, was Union Pacific Railroad train crew fatigue that resulted in the failure of the engineer and conductor to appropriately respond to wayside signals governing the movement of their train. Contributing to the crewmembers' fatigue was their failure to obtain sufficient restorative rest prior to reporting for duty because of their ineffective use of off-duty time and Union Pacific Railroad train crew scheduling practices, which inverted the crewmembers' work/rest periods. Contributing to the accident was the lack of a positive train control system in the accident location. Contributing to the severity of the accident was the puncture of a tank car and the subsequent release of poisonous liquefied chlorine gas.

The safety issues identified during the investigation of this accident are as follows:

- Train crew fatigue and
- The vulnerability, under current operating practices, of railroad tank cars carrying hazardous materials.

As a result of its investigation of this accident, the National Transportation Safety Board makes safety recommendations to the Federal Railroad Administration, the Union Pacific Railroad, the Brotherhood of Locomotive Engineers and Trainmen, and the United Transportation Union. In addition, the Safety Board reiterates six safety recommendations previously issued to the Federal Railroad Administration.

Factual Information

Accident Synopsis

About 5:03 a.m., central daylight time,¹ on Monday, June 28, 2004, a westbound Union Pacific Railroad (UP) freight train traveling on the same main line track as an eastbound BNSF Railway Company (BNSF) freight train struck the midpoint of the 123-car BNSF train as the eastbound train was leaving the main line to enter a parallel siding. The accident occurred at the west end of the rail siding at Macdona, Texas, on the UP's San Antonio Service Unit. The collision derailed the 4 locomotive units and the first 19 cars of the UP train as well as 17 cars of the BNSF train. (See figure 1.) As a result of the derailment and pileup of railcars, the 16th car of the UP train, a pressure tank car loaded with liquefied chlorine, was punctured. Chlorine escaping from the punctured car immediately vaporized into a cloud of chlorine gas that engulfed the accident area to a radius of at least 700 feet before drifting away from the site. Three persons, including the conductor of the UP train and two local residents, died as a result of chlorine gas inhalation. The UP train engineer, 23 civilians, and 6 emergency responders were treated for respiratory distress or other injuries related to the collision and derailment. Damages to rolling stock, track, and signal equipment were estimated at \$5.7 million, with environmental cleanup costs estimated at \$150,000.



Figure 1. Post-derailment pileup.

¹ All times are central daylight time unless otherwise noted.

Events Preceding the Accident

BNSF Train MEAP-TUL-126-D

The struck BNSF train, officially designated MEAP-TUL-126-D, originated in Eagle Pass, Texas, and was destined for Tulsa, Oklahoma. At the time of the accident, a two-person (engineer and conductor) crew was operating the train.

The BNSF crew had gone on duty in San Antonio, Texas, at 8:15 p.m. on June 27, 2004, the evening before the accident. Their first assignment was to relieve the crew of an empty hopper train and bring that train from Hondo, Texas, to San Antonio, a distance of 42 miles. After arriving with the train in San Antonio, the crew was then transported (by a taxi service under contract to the railroad) the 60 miles to Seco, Texas, where they relieved the crew of the accident BNSF train with the expectation of bringing the train to San Antonio. The train consisted of 123 empty cars and no loads. The train's tonnage was 4,065 tons, and its length was 7,080 feet.

According to the engineer, the dispatcher notified the crew while they were en route that they would not be continuing to San Antonio. Instead, they would tie down (secure their train) in the siding on the south side of and parallel to the main line at Macdona. A taxi service vehicle would be waiting at the siding to take the crew to the terminal.

UP Train MHOTU-23

The UP accident train, officially designated MHOTU-23, originated in Houston, Texas, on June 26, 2004, and was destined for Tucson, Arizona. At San Antonio, 54 cars were removed from the inbound train, and 30 cars were added to create the accident consist of 74 loads and no empties. The inbound four-locomotive consist remained unchanged, and the train was now about 5,464 feet long. Outbound air brake and two-way end-of-train (EOT)² tests were completed at 12:40 a.m.

The two-person (engineer and conductor) outbound crew, which was to take the train as far as Del Rio, Texas, reported for duty at 2:45 a.m. on June 28, 2004, at the UP's Kirby Yard in San Antonio. As the conductor was picking up the paperwork for the train, he met and talked briefly with the manager of yard operations. The manager observed, but did not speak with, the engineer. UP rules did not require a face-to-face meeting between supervisory personnel and a train crew before a job assignment. After picking up the paperwork for their train, the crew were taken by van to the UP's East Yard, where they boarded the train. Train MHOTU-23 began the 154-mile trip to Del Rio about 4:03 a.m.

² The EOT telemetry device transmits pertinent information, including brake pipe pressure at the rear of the train, to the lead locomotive. Two-way EOTs can also activate braking from the rear of the train.

The Accident Trip

Movements over main line track on the Del Rio Subdivision (the portion of the San Antonio Service Unit where the accident occurred) are governed by wayside signals and power-operated switch machines, both of which are controlled through a centralized traffic control system operated by a dispatcher at the UP dispatch center in Spring, Texas. The wayside signals along the main track are designed to sense the presence of trains within a defined “block” of track and automatically display the appropriate signals to other trains that may be approaching the occupied block. (Signal indications can also be controlled by the train dispatcher, as discussed in the “Tests and Research” section of this report.)

For example, under this system, if a train is present anywhere within a particular block of track, the wayside signal immediately before the occupied track segment will display a red aspect, indicating *stop*. At the same time, the signal immediately preceding the *stop* signal will display a steady yellow aspect, indicating *approach*. Similarly, the signal immediately preceding the *approach* signal will display a flashing yellow aspect, indicating *advance approach*. As a train moves along the main line, sequentially occupying and vacating track segments, the signals respond accordingly, giving warning to any trailing or opposing trains. (See figure 2.) Railroad operating rules dictate the actions a train crew must take in response to signal indications encountered en route. On the UP, the following rules apply:³

Indication	Action
<i>Advance approach</i> (flashing yellow)	Proceed prepared to stop at the <i>second</i> signal. Freight trains exceeding 40 mph must immediately reduce to 40 mph.
<i>Approach</i> (steady yellow)	Proceed prepared to stop before any part of train or engine passes the <i>next</i> signal. Freight trains exceeding 30 mph must immediately reduce to 30 mph.
<i>Stop</i> (red)	Stop before any part of train or engine passes <i>this</i> signal.

About 30 minutes after departing Kirby Yard, the accident UP train stopped near milepost (MP) 214 to allow a Laredo-bound UP train to proceed ahead of it and depart onto the Laredo Subdivision. After the stop, at recorder time 4:35:20 a.m., the engineer moved the throttle from idle to notch 1, then gradually to notch 4.⁴

³ The speeds specified under these rules are the maximum speeds permissible under any circumstances; they are not necessarily appropriate and safe for every location. Depending on the topography, track layout, signal location, type of train, and train weight, the maximum safe speeds may be significantly below those specified, and train engineers are expected to operate their trains accordingly.

⁴ The information in this section regarding train operation is based on event-recorder data. The UP train engineer said he had no recollection of the accident trip until after the collision. He therefore could not assist in reconstructing the accident scenario.



Figure 2. Portion of Union Pacific Railroad main line between San Antonio, Texas, and accident site at Macdona. Signals are identified with indications displayed for accident Union Pacific Railroad train.

The accident train continued westbound, with the throttle handle manipulated between idle and notch 4 and the speed fluctuating but remaining under 20 mph. After the Laredo train had diverted to the south, about 4:49, the engineer moved the throttle to notch 5. At 4:52:33, the train proceeded past the *clear* signal at Withers, traveling 44 mph with the throttle in notch 4.

While still in throttle notch 4, the train speed increased to 49 mph,⁵ after which the throttle was gradually decreased until, at 4:54:01, the throttle was in idle. About 11 seconds later (4:54:12), the train passed the signal at Alamo Junction, which was displaying a *clear* indication. At this time, the train was traveling 46 mph with the throttle remaining in idle. During this portion of the trip, the accident train traversed two rail/highway grade crossings without its horn being sounded, as required by UP operating rules.

The speed continued decreasing with the throttle in idle. At 4:55:17, with the speed indicating 37 mph, the throttle was moved from idle to dynamic braking.⁶ Less than a minute later, with the train speed at 31 mph, the throttle was moved back to idle for 6 seconds before being increased to notch 1. The train proceeded past the next signal, which was displaying *advance approach* (because the eastbound BNSF train on the same track was nearing the west end of the siding at Macdona), at recorder time 4:57:25. The train was traveling 22 mph with the throttle in notch 2. The train speed decreased to 21 mph until 4:58:13, when the throttle was moved to notch 4. At 4:59:35, the throttle was placed in notch 5, and the train speed began to increase.

The Accident

The UP train traveled past the signal at the east end of the Macdona siding, which was displaying an *approach* indication (the BNSF train was about 1 minute away from the west end of the siding), at recorder time 5:00:55 a.m. with the speed indicating 46 mph. The engineer reduced the throttle to notch 4, and as the BNSF train was entering the west end of the siding at 5:01:47, the speed of the UP train had decreased to 44 mph. (The engineer later told investigators that, with the fairly short distance between signals and the limited sight distance because of the curve, he would normally slow to about 10 mph if this signal was displaying *approach* in order to be able to stop before the next signal if necessary.)

Within the next minute, the horn was activated three times for 2- to 3-second intervals.⁷ Four seconds later (5:02:52), the throttle was moved to notch 3 with the speed still indicating 44 mph. This was the last recorded control input before the accident.

⁵ The maximum authorized speed over this track segment was 50 mph.

⁶ *Dynamic braking* is a method of train braking in which the locomotive's traction motors are converted to electric generators driven by kinetic energy from the moving train. The generated electricity flows into a resistor grid on the locomotive and is dissipated as heat. This electrical "load" on the traction motor/generator acts to slow the motor shaft rotation, resulting in a braking action being applied to the train wheels.

⁷ The engineer stated during the public hearing after this accident that he habitually sounded the train horn three times while exiting the curve at the Macdona siding to warn anyone near the track of the presence of the train.

After the last sounding of the horn, the head end of the westbound UP train on the main line passed the head end of the BNSF train that was eastbound on the adjacent siding track. The BNSF crew stated that they dimmed their train's headlight as the westbound UP train approached but that the UP train's headlight remained on bright.⁸ The BNSF crew stated that they were unable to see anyone in the UP locomotive cab, but they noted that the UP train seemed to be going too fast.

Event recorder data showed that between 5:03:17 and 5:03:19, the UP train's emergency braking automatically activated, and the train's recorded speed dropped from 44 mph to 0. The investigation later determined that the UP train had passed the *stop* signal at the west end of the Macdona siding, struck the 63rd car of the BNSF train, and derailed near the west siding switch. (See figure 3.)

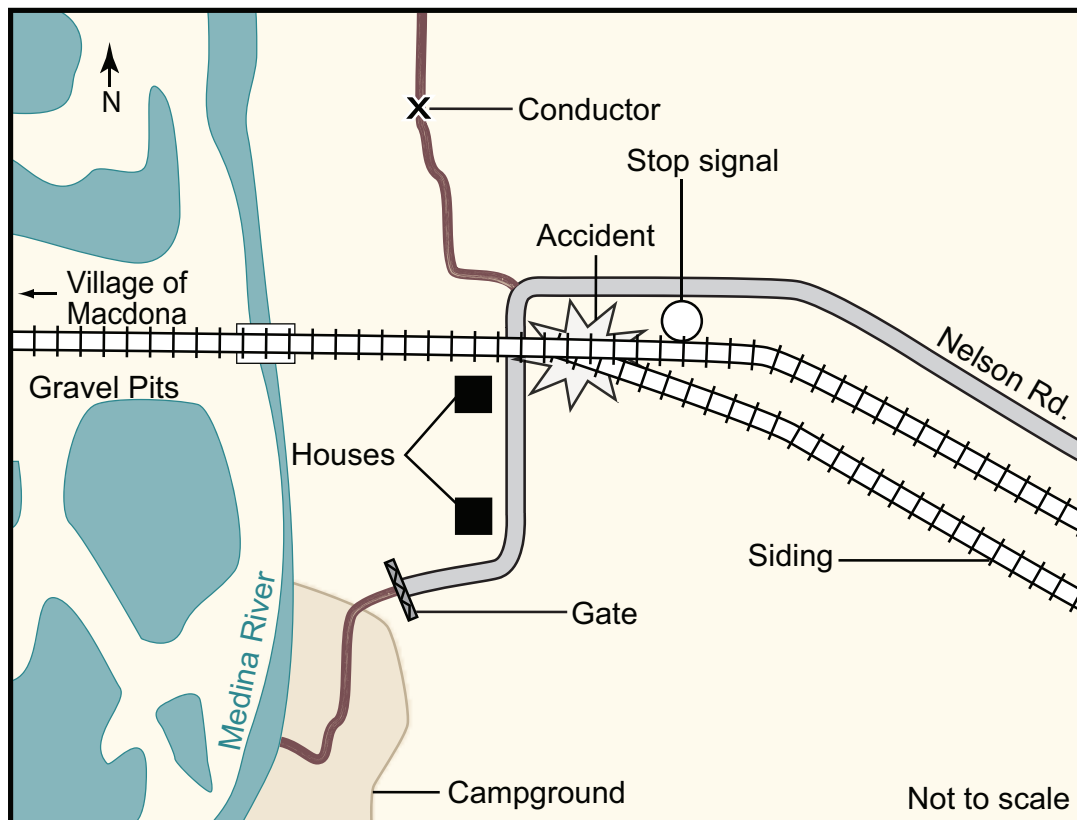


Figure 3. Accident site showing point of collision, driveway leading off Nelson Road where conductor was found, and houses where residents were trapped by gas cloud.

At 5:04:26, the UP train control system log at the UP's Spring, Texas, dispatch center showed a loss of communication with the west siding switch and signal circuits at Macdona. After an unsuccessful attempt to reset the control system, the dispatcher

⁸ *General Code of Operating Rules* Rule 5.9.1 requires that a train's headlight be dimmed "when approaching and passing the head end of a train on the adjacent track."

attempted to radio the crew of the UP train but received no answer. About 5:07 a.m., one of the BNSF train crewmembers radioed the UP train dispatcher to report an automatic application of his train's emergency brakes (when the collision separated the train at the 63rd car). At that time, he said, he checked his distance counter and noted that his train was about 3,200 feet into the siding. About 5:08 a.m., one of the BNSF train crewmembers radioed the UP train dispatcher that the UP train on the main line track had been "coming by us hot [fast]," but was now stopped. He told the dispatcher that he would walk back along his train, toward the head end of the UP train, to assess the situation. The dispatcher, who had been attempting to contact the UP crew by radio, said he would dispatch emergency resources to the location.

As a result of the collision, the 4 locomotive units and the first 19 cars of the UP train derailed, as did 17 cars of the BNSF train. As the UP cars derailed and piled up to the north of the main line track, the 16th car of the train, a pressure tank car loaded with liquefied chlorine, was punctured. Chlorine escaping from the punctured car immediately vaporized into a cloud of chlorine gas that engulfed the accident area.⁹

At 5:14 a.m., the BNSF crewmember, in an emergency radio transmission to the UP train dispatcher, said he could see smoke coming from the head end of the UP train at the west end of the siding. He told the dispatcher he believed that the UP train had "run through" the signal and collided with the side of the BNSF train. He reiterated a request for assistance at that location. The UP train dispatcher told him that responders had already been notified.

The BNSF crewmember returned to his locomotive cab, where the BNSF dispatcher had instructed the crew to remain. Shortly thereafter, the BNSF crew were contacted by a UP trainmaster and told to leave the locomotive and walk east where he would pick them up. Once they were debriefed by the trainmaster, they were taken for mandatory postaccident toxicological testing. The BNSF crew had been more than 3,000 feet east of the collision and derailment and were not affected by the chlorine leak.

The UP engineer said his first recollection regarding the accident was feeling the locomotive "shaking" and realizing that his left foot was pinned under some debris.¹⁰ The engineer recalled that after the collision, the conductor asked what had happened, and he told him, "We hit another train." He said an odor became evident and he knew they had to leave. He said he remembered freeing his foot and helping the conductor through the front window. He said he followed the conductor out the window, after which the two men walked together along a road (an unpaved driveway extending from Nelson Road) to the west and away from the accident site. He said the conductor was having difficulty

⁹ According to the Environmental Protection Agency, the concentration of chlorine gas in the air surrounding the accident site may have reached 400,000 parts per million. The National Institute of Occupational Safety and Health immediately dangerous to life and health (IDLH) threshold for chlorine is 10 parts per million.

¹⁰ The engineer was interviewed on two separate occasions about the accident and about his actions immediately afterward. The accounts provided by the engineer at the two interviews differed slightly in chronology and in minor details. The account presented here is a composite of the two interviews, and while it addresses the essential activities, the chronology may not be exact.

breathing; and when they came to an area where the gas seemed to be less intense, the conductor sat down.

The engineer stated that he continued walking until he found himself in a wooded area, after which he returned to the conductor. He said the two began walking in the other direction, but they had not gone far when the conductor could not continue. He said he attempted to lift and carry the conductor out of the area but was unable to do so. The engineer stated that he continued to walk eastward, passing to the north of the accident pileup. He said he happened upon an automobile and, believing the air would be “cleaner” inside the car, climbed in and closed the door. He quickly realized that he was still in danger because of the gas, so he left the car and continued walking east (along Nelson Road).

Emergency Response

The initial notification to local emergency response authorities came via a 911 call placed at 5:06 a.m. from a residence on Nelson Road to the Bexar County 911 Emergency Call Center. The caller reported difficulty breathing and the presence of white smoke outside the residence. The caller also, in what could be described as a weak voice, referred to a train derailment. The 911 operator heard the word “smoke” and understood that the caller was experiencing breathing difficulty but apparently did not recognize the words “train derailment,” and the caller was transferred to a fire department dispatcher. The caller again reported “train derailment” and “smoke,” but the fire dispatcher also did not recognize that the incident involved a train derailment. The response was thus processed as a “difficulty breathing and smoke in the residence” response action.

The principal agency responsible for responding to emergencies, including hazardous materials incidents, within the Macdona District of Bexar County, where the accident occurred, was the Southwest Volunteer Fire Department. Fire department emergency responders were dispatched to the Nelson Road residence at 5:08 a.m., followed shortly thereafter by Bexar County Sheriff’s Office patrol units that had been dispatched for support. None of the responders were yet aware that they were responding to a train accident and that their path to the Nelson Road residence was blocked by derailed equipment.

When fire department responders approached the accident site in darkness about 5:15 a.m., they began to have difficulty breathing as they became exposed to the vapor cloud of chlorine from the punctured railcar. They immediately withdrew from the scene and requested mutual aid from other agencies. Some of the firefighters obtained protective clothing and self-contained breathing apparatus, and commencing about 5:40 a.m., then reentered the scene to conduct a search for survivors.

The initially requested mutual aid resources began to respond to the scene shortly thereafter, which included the Bexar County Office of Emergency Management. About 6:10 a.m., the Bexar County Office of Emergency Management established the unified (incident) command system, activated the Bexar County Emergency Operations Center,

and initiated the Bexar County emergency management plan. Additional mutual aid resources were also being dispatched to the scene, including the San Antonio Fire Department.

About 6:15 a.m., Southwest Volunteer Fire Department officers, who were advancing west along Nelson Road, came upon an individual who would later be identified as the UP train engineer stumbling along the roadway about 240 feet east of the grade crossing. He was in respiratory distress and was transported from the scene for medical attention. A short time later, responders determined that the derailment wreckage at the grade crossing prevented access to residences at the west end of Nelson Road, one of which was their dispatch destination. The obstructed grade crossing also prevented the immediate rescue of three individuals who were reported to be trapped in their residence by the vapor cloud several hundred feet to the south of the emergency dispatch destination.

Responders told investigators that early in the response effort they considered, then rejected, a plan to use a helicopter to access Nelson Road south of the grade crossing and evacuate the two occupied residences there. They decided that such a plan was ill-advised until the gas plume had reduced or stabilized because of the vulnerability of the helicopter equipment and crew and the possibility that rotor wash could spread the gas.

Commencing about 6:33 a.m., hazardous materials response contractors retained by the UP began to arrive and conduct a technical assessment of the chlorine release. Further access to the accident site through the wreckage pileup at the grade crossing area was restricted until the assessment could be made and appropriate personal protective equipment (principally level-A hazardous materials suits) could be donned by firefighters and hazardous materials personnel. Sunrise occurred at 6:37 a.m., and the wind was moderate but steady toward the northwest.

An evacuation zone was established around the accident site with a radius of about 2 miles. Other than assisting with the evacuation of residents within the evacuation zone and assisting hazardous materials release mitigation responders with the technical assessment of the chlorine gas release, no further direct rescue attempt activity of the responding firefighters and mutual aid responders for the three individuals who were reported to be trapped in their residence by the vapor cloud was documented for about the next 3 hours. During this time, pursuant to 911 call center instructions, the three residents were attempting, without success, to flee and find a safe shelter from the chlorine fumes that had engulfed their residence. Also during this time, according to postaccident interviews, the principals of the primary responding emergency services agencies (the San Antonio Fire Department, the Bexar County Office of Emergency Management, and the Southwest Volunteer Fire Department) were involved in what was described as a certain amount of discordant debate regarding jurisdictional boundaries and incident command authority.

About 9:45 a.m., with a preliminary technical assessment of the chlorine gas release having been completed, the first of three firefighter "entry teams" entered the accident area to attempt a rescue of three trapped persons on Nelson Road who were unable to escape the chlorine vapor cloud that had enveloped their residence. This first

entry team, however, became disoriented while attempting to advance through the wreckage pileup and inadvertently diverted down the wrong roadway (actually a long driveway leading to another residence) and away from their objective. Along that roadway, the team encountered the body of a person who was later identified as the UP train conductor. Shortly thereafter, one of the entry team firefighters showed signs of dehydration, prompting the dispatch of a second entry team to come to the aid of the first.

About 10:12 a.m., a third entry team, consisting of two firefighters and one UP employee, was dispatched to carry on with the rescue mission that had been aborted by the first entry team. This team successfully advanced through the wreckage pileup and, about 10:55 a.m., reached the three persons who had been trapped at their residence by the gas cloud. All three were found to be in considerable respiratory distress. About 11:46 a.m., after the responders had revived and stabilized them, the three individuals were transported by helicopter to a local hospital for medical attention.¹¹ About 11:55 a.m., the entry team entered another Nelson Road residence and found two persons who had sustained fatal injuries.

Injuries

Three persons died from chlorine gas inhalation as a result of the accident. One was the UP train conductor; the other two were occupants of a residence about 220 feet south of the grade crossing on Nelson Road.

The UP train engineer, though critically injured, survived the collision and the exposure to the chlorine vapor. Investigators reviewed medical records to identify 23 civilians who were treated at local medical facilities for respiratory distress or other ailments likely associated with the gas release or its aftermath. Local media reported other individuals as receiving medical treatment after the accident, but investigators were unable to locate medical records that would confirm the count.¹²

Investigators identified six emergency responders who were either treated at the scene or transported to local medical facilities. Two of these were firefighters who were treated at a local hospital for respiratory difficulties and released. Two other firefighters were treated on scene for dehydration. One Bexar County Sheriff's Office deputy officer was treated for respiratory difficulty at a local hospital and released. The sixth injured responder, an ambulance attendant, was treated at a local hospital and released. Two UP technical support employees received treatment at local medical facilities for respiratory distress most likely associated with exposure to the chlorine gas.

¹¹ The air quality at the helicopter landing zone was determined to be sufficiently clear by that time, such that it was not a threat to helicopter operations.

¹² As many as 40 people were initially reported to have been transported to medical facilities. This may include an unknown number of people who used their own transportation and reported to their personal physicians or to other medical facilities for treatment. This number may also include some individuals who presented at a medical facility for treatment but were subsequently found not to have ailments associated with exposure to the chlorine release.

The concentrated chlorine vapor cloud was later determined to have a defined radius (as measured from its origin) of at least 700 feet.¹³ The vapor cloud drifted with the wind from the accident site and traveled in a northwesterly direction toward several residential areas within the city of San Antonio. A large commercial entertainment venue (Sea World) about 10 miles northwest of Macdona was in the path of the chlorine vapor cloud. Several employees of the facility reported becoming slightly ill, and several persons were reported to have been transported to a local medical facility as a result of exposure to chlorine vapors.

Damages

UP Lead Locomotive

The lead locomotive unit of the UP train came to rest lying on its left side a short distance to the northwest of the Nelson Road grade crossing. The unit was longitudinally oriented at about a 30° angle relative to the track, with its cab end skewed away from the track and its other end resting relatively close to the track. The front of the locomotive unit was an estimated 102 feet west of the Nelson Road grade crossing (measured from the edge of the pavement) and about 50 feet north of the main line track. The trailing end of the unit was an estimated 30 feet west of the grade crossing and about 10 feet north of the main line track, a total distance of about 387 feet from the approximate point of collision.

Because of limited access to the site, the locomotive could not be fully examined until it was upright in the open field to the south of the tracks adjacent to the Nelson Road grade crossing. The cab compartment was relatively intact and did not sustain significant loss of survival space. Collision damages revealed that the lead locomotive unit had struck the 63rd car of the BNSF train, which was an empty boxcar measuring about 67 feet long and 17 feet high.

Tank Car Damages

Among the 123 empty cars on the BNSF train were 14 tank cars containing residues of anhydrous ammonia, phosphoric acid, and alcoholic beverages. None of these cars derailed or were otherwise involved in the accident.

The UP train consist included 8 tank cars (the first 7 cars behind the locomotives and the 16th car), all of which derailed as a result of the collision. Cars one through seven each contained 0.05 percent ammonium nitrate solution, which is not a hazardous material regulated by the U.S. Department of Transportation (DOT). These cars collectively released about 78,200 gallons of ammonium nitrate solution.¹⁴

¹³ This determination was based on the extent of foliage kill in the area.

¹⁴ The entire loadings were released from the first and seventh cars, and partial loads were released from the second and fifth cars. The third, fourth, and sixth cars retained their loadings.

The punctured 16th car, containing chlorine, came to rest with its manway facing south and rotated 20° from the vertical, with its A-end¹⁵ facing west and slightly lower than the B-end. The B-end coupler remained coupled to the 17th car, a hopper car.

Three days after the accident, Safety Board investigators inspected the punctured car. At the time of inspection, the tank had been moved about 20 feet south of its original location and had been rotated such that the manway was oriented 90° from the vertical. Hazardous materials responders estimated that about 60 percent (about 9,400 gallons) of the original load of liquid chlorine had been released.

The right corner of the A-end had sustained two dents. One was a 4-inch-deep dent in the lower quadrant of the head (the curved end) of the tank. This dent contained a 2-inch by 11-inch puncture, which terminated 1 inch beyond the seam joining the tank head to the tank shell. The response team had plugged the puncture with wooden wedges during the initial response. The second dent had overall dimensions of 34 inches by 58 inches. This dent contained a rectangular impression measuring approximately 2 inches by 58 inches. There was no evidence of additional damage to the remainder of the tank head, shell, or pressure-retaining components of the car. (See figure 4.)

Flatcar Damages

Four of the derailed cars of the UP train (cars 12 through 15) were flatcars transporting steel plates. The trailing ends of three flatcars (the 12th, 13th, and 15th cars) came to rest adjacent to the derailed and punctured chlorine tank car. The side frame member and deck plate at the left side of the B-end of the 12th car were found to have been displaced 53 inches rearward and 36 inches inward. Shards of yellow foam-like material were embedded in several areas along the outer edges of the deformed deck plate. The leading edge of the deck plate also contained scuff marks in a semicircular pattern. The 13th car came to rest at least a car-length away from the derailed chlorine tank car.

Of the four derailed flatcars, only the 15th car, which was just ahead of the punctured chlorine tank car in the train consist, retained its load during the accident. The car was a bulkhead flatcar loaded with seven steel plates, each measuring 43 feet by 10.5 feet by 1.75 inches and weighing about 26,000 pounds. Post-derailment inspection revealed that all of the steel plates remained secured to the flatcar; however, two of the four steel securement bands had broken.

Monetary Damages

Monetary damages from the accident were estimated as \$4,911,397 for locomotives; \$555,342 for railcars; \$184,025 for track; and \$50,000 for signals. These estimated damages totaled about \$5,700,764. These estimates do not include the cost of lading carried by the cars and environmental cleanup. According to the UP environmental site remediation manager, the cost associated with the environmental cleanup was approximately \$150,000.

¹⁵ The *A-end* of a railcar is the end opposite the *B-end*, which is the end with the handbrake. On the 16th car, the A-end was the leading end.

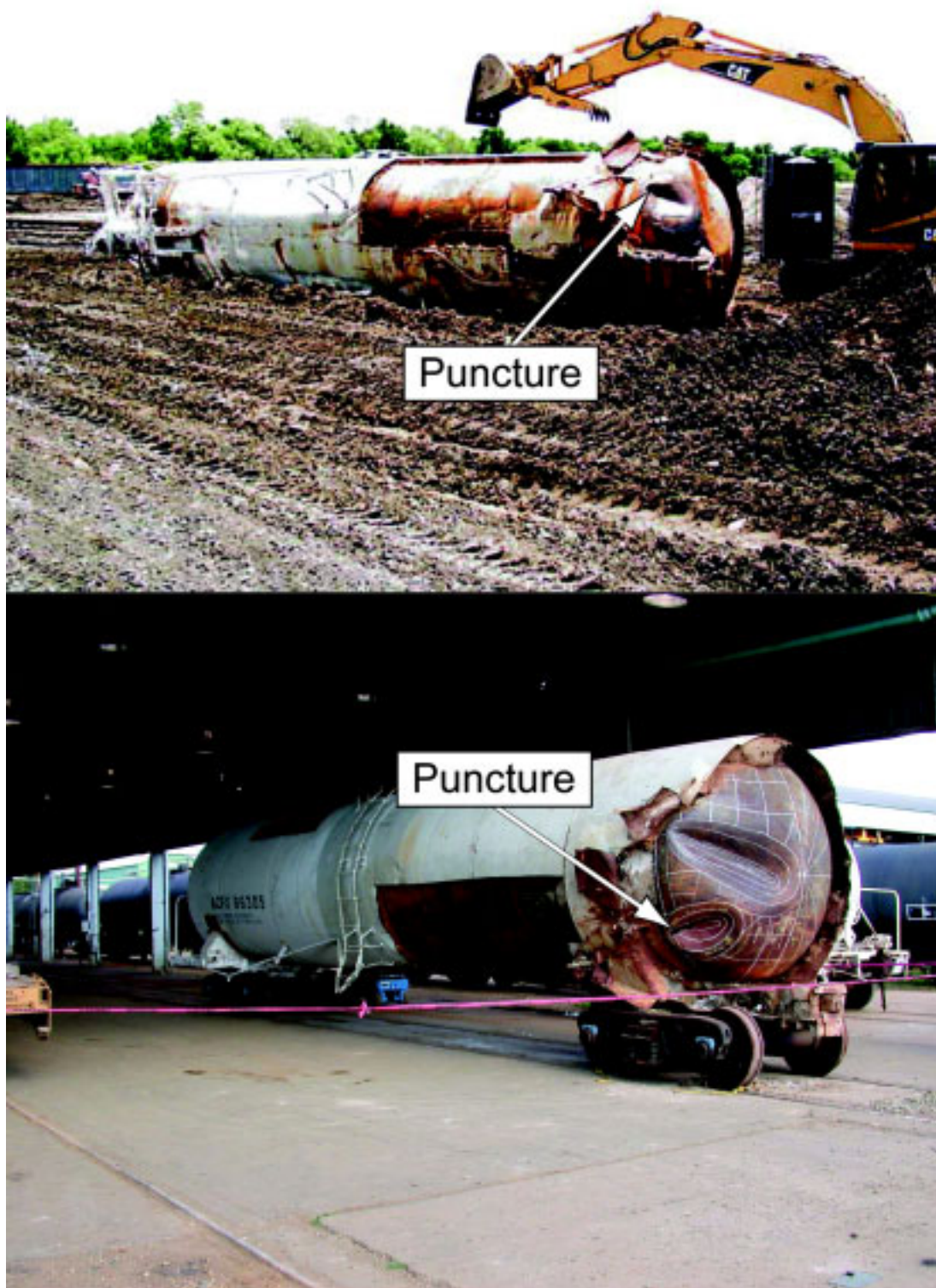


Figure 4. Punctured chlorine tank car at accident site (top) and after recovery (bottom).

UP and contractor personnel conducted the environmental remediation, which included application of agricultural lime to treat the acidic soils caused by the chlorine release and vacuum truck recovery of pooled diesel fuel. Areas affected by the diesel fuel were scraped to a 6-inch depth. Seventy truckloads of hydrolyzed chlorine and ammonium nitrate contaminated soils were removed from the site for disposal.

Personnel Information

The UP Engineer

The engineer of the UP train, age 37, was hired on March 16, 1998. Within the first 7 months on the job, he was trained and worked as a brakeman and conductor and then entered training to become an engineer. He was first certified as an engineer on October 29, 1999, and had been recertified on March 23, 2004. At the time of the accident, he was assigned to a regular freight crew pool¹⁶ for trains operating between San Antonio and Del Rio. UP records for the engineer showed one failure of an efficiency test during the year before the accident. The UP engineer's most recent rules examination had been on March 15, 2004, and his most recent observed (by a railroad official) operation of a locomotive was June 14, 2004. UP records showed no exceptions taken to his operating performance since his hire, and he had not been the subject of any disciplinary action.

The engineer's most recent physical examination had been on February 27, 2004. He said that he had 20/50 vision in his left eye and that he wore prescription glasses while working. He said that he kept himself in physical condition by running, weightlifting, occasional biking, and walking when playing golf and that, in the months before the accident, he had been preparing for entering triathlon and marathon competitions.

The engineer told investigators that in the month before the accident he had been sleeping at the home of another engineer while he looked for an apartment. He said that his "normal" sleep time was 7 hours but that he did "OK" on 4 or 5 hours, depending on his work the previous day.

The UP Conductor

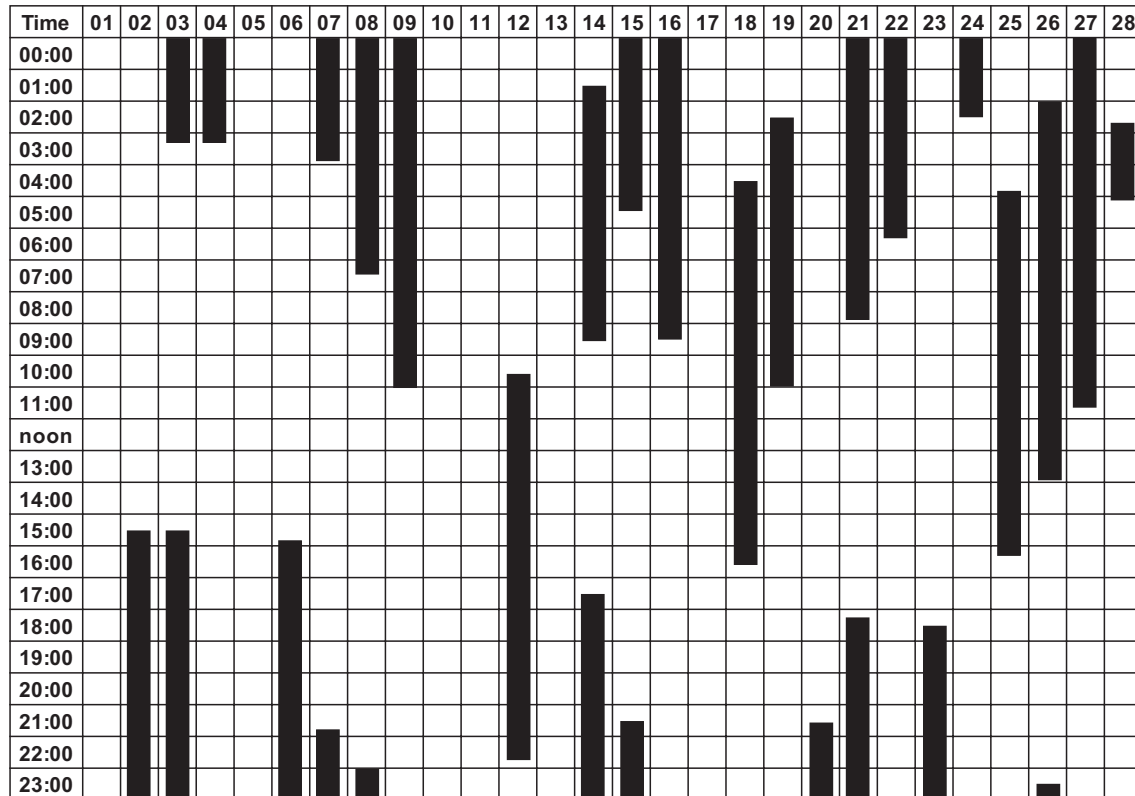
The conductor of the UP train, age 23, was hired on July 22, 2002, and was promoted to conductor on January 10, 2004. He had received and passed a UP medical examination on February 14, 2002, and had no disciplinary actions on his record. The son of a UP engineer, the conductor planned to become an engineer himself. He anticipated starting a training class in July 2004 and, according to a close friend, had received study materials for the engineer class the week of the accident.

¹⁶ A crew working in *pool service* catches the next available train on a first-in-first-out basis.

The UP Crew's Work Schedule and Activities Before the Accident

UP Engineer. The UP train engineer's work schedule for the first 3 weeks of June 2004 is shown in table 1.

Table 1. UP engineer's work history June 1-28, 2004.



Black bars indicate hours on duty.

As recorded by the UP crew caller system, the engineer, at the end of his work shift on Saturday afternoon, June 26, 2004, called the crew management office and asked a crew caller about the possibility that he would be called to work locally in San Antonio the next day. He told the crew caller that he needed personal time on Sunday afternoon because he was going to pick up his daughter at the airport. The crew caller told the engineer that he would possibly be called locally to relieve a crew that had reached their maximum hours of service outside the terminal limits. The engineer said he would have to lay off (formally make himself unavailable for work) if he did not get a local job, and the crew caller gave him the option of taking 12 hours' undisturbed rest instead. The engineer declined and said he would call later to see if a local job was available. The engineer also asked the crew caller to make a note for other callers that he would be picking up his daughter Sunday afternoon.

The engineer was called to report for work at 11:30 p.m. on Saturday evening and worked until 11:30 a.m. on Sunday. UP computer records show that when the engineer completed work on Sunday, he used the company's computer system to request 12 hours of undisturbed rest. Once the computerized crew management system accepted the

request, the system would not show the engineer as available to be called for work until the expiration of the 12-hour rest period.

At the time of the accident, the engineer was separated from his wife and was looking for an apartment. During that time, he was sleeping at the home of another engineer but was spending most of his waking hours elsewhere.¹⁷ The engineer said that after he went off duty on Sunday morning (and requested 12 hours' rest), he drove from Kirby Yard to his wife's home, about 15 minutes away. He said he went there to visit with the couple's daughter, who was returning home after visiting a college out of town. He said that when he arrived, he learned that his daughter would not be arriving until 6:00 p.m., so he spent the next 4 to 4 1/2 hours watching television and napping on the couch. After picking up his daughter at the airport, he took her back to his wife's home, where they had dinner. He said he left there about 8:30 p.m. and went to the home of a friend to play cards. He said he returned to the home of his engineer friend and went to bed between 11:00 and 11:30 p.m. Sunday evening.

The engineer said he did not believe he would be called to work until later Monday morning and was thus expecting to receive several hours' rest when he went to bed. UP records show that the engineer made four calls to the automated voice response system¹⁸ on Saturday. He made no calls to the system on Sunday.

At 12:38 a.m. on Monday, June 28, about 1 to 1 1/2 hours after the engineer said he went to bed, he was called by the railroad crew caller. An audio recording of the conversation confirmed that the crew caller told the engineer that he was being contacted according to designated vacancy procedures and asked him if he would accept the assignment. The engineer agreed without further comment and was given an on-duty time of 2:45 a.m.

At the April 2005 public hearing on this accident, the engineer said:

I don't believe that there is discipline if they call you and you're not scheduled to go to work. The problem is, the board gets rolled so often that you never know if it's your turn or not. I could be 15 times out and miss calls because they rolled the board and put me first out. So if the phone rings and it's [the railroad call office], I'll answer it.

The residence where the engineer was staying was about 20 minutes from Kirby Yard, and he was observed on the property at about 2:30 a.m. As he walked from the parking area to the yard office, he encountered an acquaintance who was also an engineer. According to the acquaintance, the two stood outside the yard office and talked from about 2:30 to about 2:40 a.m. The acquaintance said the engineer told him about having spent some time during

¹⁷ The engineer told investigators he did not want to impose on his friend, so he made it a point to spend his waking hours away from his friend's residence.

¹⁸ A railroad employee can telephone the automated voice response system (part of the railroad's crew management computer system) to receive information about known vacancies, the lineup of scheduled trains, and the employee's standing among crews or individuals available for work. The same information can be accessed via the UP's Web site.

the day with his daughter. He said the engineer appeared tired and that he mentioned feeling tired.¹⁹

When he was later asked about fatigue on the job, the engineer stated that he did not recall ever having been too tired to report for work, but he said:

If you were to take a poll, most of the people at work are tired. I mean, you work so often, so many different shifts, your body really doesn't recuperate.

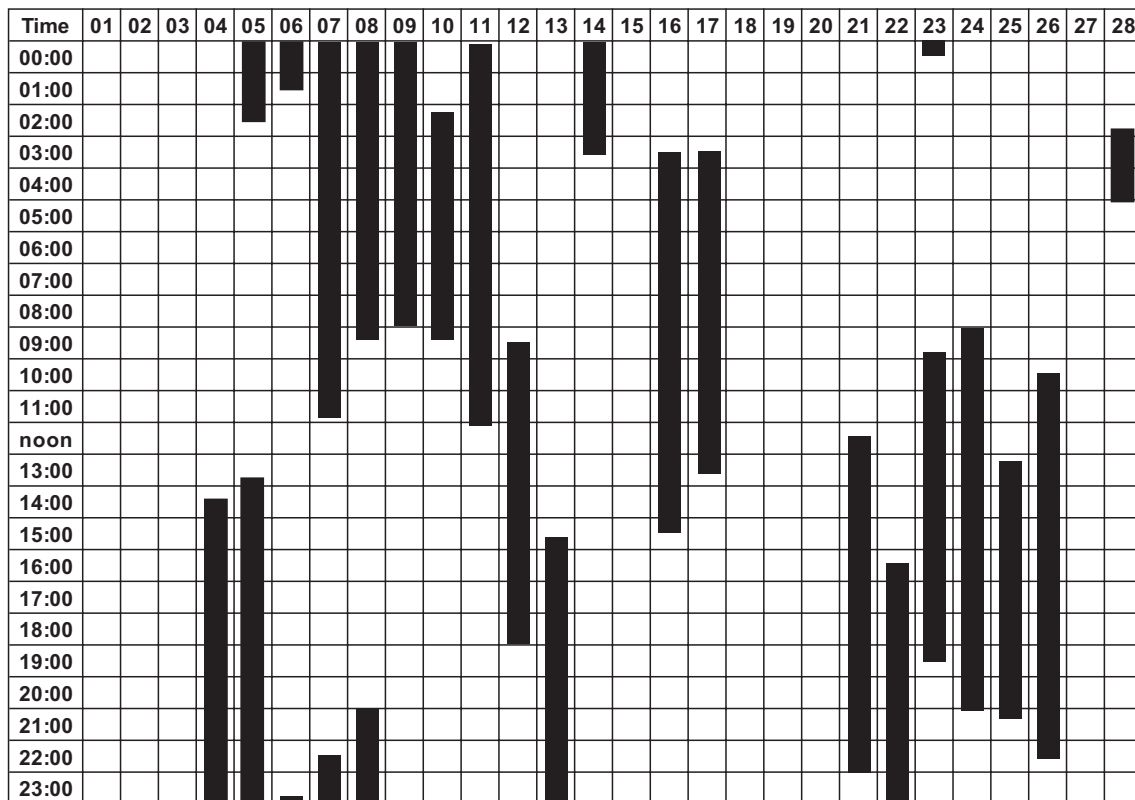
The acquaintance said the engineer told him that he had taken the call for the job because he expected that more calls would follow and that he would have been unable to sleep anyway. At the public hearing, a UP official stated that, based on the engineer's standing on the board and the way trains were called, it appeared that the engineer would have been called about 6:40 a.m. Monday morning had he not accepted the earlier call. At the time the engineer reported for duty on June 28, he had been off duty for 14 hours 15 minutes.

UP Conductor. The UP train conductor's work schedule for the first 3 weeks of June 2004 is shown in table 2.

A friend who lived with the conductor told investigators that he adhered to a routine during his off-duty time. She said he would typically shower as soon as he got home and then check the UP Web site for the time he would likely be called to work again. She said he would then go to bed, expecting to get about 6 hours of uninterrupted sleep before his next call to work. She said that when the conductor returned home after work on Friday, June 25, about 10:30 p.m., he expected to be called as soon as he was legally rested, so he went directly to bed.

The friend recalled that she had rented a movie for them to watch when the conductor returned home from work about 10:30 p.m. on Saturday evening. She said the conductor checked the Web site about 1:00 a.m. on Sunday morning to see when he might be called to work. Afterwards, the two watched television before retiring about 4:00 a.m. They got up about 1:00 p.m. on Sunday and went out for dinner. After they returned home, the conductor checked the UP Web site again and told his friend that he was "second or third out." She said they watched television and talked for the rest of the afternoon.

¹⁹ The engineer told investigators he could not remember anything that occurred from the time he went to bed until after the collision. He therefore did not remember the discussion described here.

Table 2. UP conductor's work history June 1-28, 2004.

Black bars indicate hours on duty.

Some time before 6:00 p.m., an acquaintance called the conductor and invited him to see a house the acquaintance had recently purchased. The friend said the conductor left about 6:00 p.m. and returned about 9:00 p.m. She said she did not know if the conductor consumed any alcohol while he was away, but he may have had “one beer” at home when he returned. The friend recalled that they watched television and talked for the rest of the evening. She said that the conductor knew he was “second out” when they went to bed. The UP automated voice response system showed that nine calls were made to the system using the conductor’s identification information between 8:18 p.m. and 11:07 p.m. on Sunday, June 26. The friend said they were awakened about 12:40 a.m. Monday when the conductor was called to report for the Del Rio train. The friend said the conductor called her about 2:30 a.m. on his way to work and again about 3:00 a.m. She said he sounded alert during both calls. At the time he reported for the accident train, at 2:45 a.m., the conductor had been off duty for 25 hours 50 minutes.

Toxicological Information

Specimens for postaccident alcohol and drug testing of the train crews were collected under the supervision of BNSF and UP railroad officials for their respective employees. The custody and control form for the BNSF engineer showed that blood was

drawn at the Lackland Air Force Base hospital emergency treatment facility at 2:42 p.m. on June 28, and urine was collected at 3:02 p.m. The BNSF conductor's blood was drawn at the same facility at 2:21 p.m. on June 28, and urine was collected at 2:49 p.m. The custody and control form for the UP engineer showed that blood was drawn and urine was collected at 5:45 p.m. on June 28.²⁰ The Federal Railroad Administration (FRA) test results for the BNSF crew and the UP engineer were negative for alcohol and drugs of abuse.²¹

The custody and control form for the UP conductor showed that postmortem specimens were obtained at 12:00 p.m. on June 29 (noted with "very mild" decomposition). FRA test results for the conductor were positive for ethanol as follows: blood concentration 0.013 percent, urine concentration 0.051 percent, and vitreous humor²² concentration 0.029 percent. Results were negative for drugs of abuse.

Two capsules containing a white powder-like material were found in the conductor's personal effects. To facilitate identification of the material, additional testing of the conductor's specimens was performed at the Federal Aviation Administration Toxicology and Accident Research Laboratory. The results were negative for the tested substances.²³

The Safety Board obtained the cooperation of the Federal Bureau of Investigation in identifying the substance in the capsules. The Federal Bureau of Investigation's chemical laboratory reported that the material was consistent with the antibiotic ampicillin. The markings on the capsules were tentatively matched with markings on 500-milligram ampicillin capsules manufactured in Mexico and marketed as Ambiosol.

Meteorological Information

The weather station closest to the accident site was at the San Antonio Stinson Municipal Airport, about 12 miles east of the scene. Observations from this station for the day of the accident documented that moonset was at 3:00 a.m. and sunrise was at 6:37 a.m. No rain accumulation was recorded, but localized thunderstorms prompted flash flood warnings for Bexar and adjoining counties overnight. At 4:53 a.m., winds were from the

²⁰ Federal regulations (49 *Code of Federal Regulations* 219.209(c)) require a written explanation when postaccident drug and alcohol tests are delayed by more than 4 hours. The delays in this case were explained by delays in transporting the crews to the test facility and the unavailability (because of the number of persons being treated for accident-related injuries) of medical staff to make timely collections of specimens.

²¹ Specimens were tested for cannabinoids, cocaine, opiates, amphetamine, methamphetamine, phencyclidine, barbiturates, benzodiazepines, and ethyl alcohol.

²² *Vitreous humor* is the clear gel-like mass within the eye that fills the space between the lens and the retina.

²³ The specimens were tested for cannabinoids, cocaine, opiates, amphetamine, methamphetamine, phencyclidine, barbiturates, benzodiazepines, antidepressants, antihistamines, meprobamate, methaqualone, and nicotine.

southeast at 5 knots. The temperature was 75° F with a dew point of 73° F. Southeast winds continued for about 7 hours after the accident.

Site Description

The Railroad

The collision occurred at MP 225.36 on the UP's Del Rio Subdivision. The subdivision is 178 miles long and extends from the UP's Kirby Yard in San Antonio to Del Rio, Texas. The single-track main line on which the accident occurred was constructed by the Galveston, Harrisburg and San Antonio Railroad. It was later operated by the Southern Pacific Railroad until that railroad merged with the UP in 1996. Also in 1996, the BNSF railroad acquired trackage rights along this main line from Eagle Pass to San Antonio.

The main line track through the area is oriented in an approximate east-west direction and is fairly level and straight, except for a slight curve to the south near the eastern end of the Macdona siding. The siding itself is 8,459 feet long and runs parallel along the south side of the main line. Although the track in the accident area was maintained as Class 4 track, which allows for maximum speeds of 60 mph for freight trains and 80 mph for passenger trains, UP Timetable No. 2, effective October 29, 2000, allowed maximum speeds of 50 mph for freight trains and 55 mph for passenger trains. At the time of the accident, a 45-mph slow order was in effect over the west siding switch because of surfacing and tamping that had been done in that area on June 25, 2004. The siding switches were approved for a maximum diversion speed of 25 mph.

The Community

Macdona is a mixed rural and suburban area of Bexar County, Texas, which is within the San Antonio metro area. The estimated metro area population in 2004 was 1,493,965. The accident occurred in an unincorporated rural area about 1 mile east of the village of Macdona and about 17 miles southwest of downtown San Antonio. A number of farms (open agricultural fields) and wooded areas are adjacent to the accident site.

A two-lane paved road, Nelson Road, runs along the north side of the main line for about 2 miles, paralleling the main line and the siding, before turning due south to cross the main line at grade near the west end of the siding (near the collision point). Several residential dwellings and small commercial facilities are situated along the road. At the point where the paved roadway turns southward to cross the track, a private driveway extends from Nelson Road and parallels the north side of the main line track. An unknown number of persons were occupying the two residences on this driveway at the time of the accident.²⁴

²⁴ The occupants left the area without using Nelson Road.

The Nelson Road crossing is a conventional rail/highway grade crossing. The paved portion of the roadway continues from the grade crossing for about 0.2 mile southward. It then turns due west and extends several hundred feet until the pavement ends at the gated entrance of a commercial recreational property. Along the paved portion of the road south of the grade crossing were two residences. The closer residence to the accident scene had a driveway entrance about 210 feet south of the grade crossing, which was also the initial destination of the emergency responders. Two occupants were in the residence at the time of the accident. The second residence, about 700 feet south of the grade crossing, had three occupants.

Beyond the gated entrance to the commercial recreational property, Nelson Road is unpaved and continues westward, passing through the commercial property and ending at the east bank of the Medina River. The Medina River flows generally in a north-to-south direction through this area and, at the time of the accident, it was partially flooded and averaging 30 to 40 feet wide. The driving distance from the firehouse (on the west side of the river) to the accident site (on the east side of the river) is about 6 miles.

Tank Car Information

The punctured tank car (ACFX 86305) had been loaded on June 10, 2004, at Taft, Louisiana, with 180,000 pounds (15,656 gals) of 30° F liquefied chlorine at 37 pounds per square inch, gauge. The tank car was being shipped to Hasa, Inc., in Eloy, Arizona.

The tank car was constructed in August 1976 by American Car Foundry Industries, Inc. The car was built as a standard 17,360-gallon DOT 105A500W specification tank car. The shell and head material was TC-128-B steel. The tank shell was 0.775 inch thick, and the head sheet was about 0.875 inch thick before forming. The tank was insulated with a 4-inch layer of urethane foam, which was covered with a 0.125-inch-thick steel jacket. In November 1992, this combination of tank thickness, foam insulation, and jacket was subjected to qualification testing and shown to meet the DOT's performance requirements for head puncture and thermal protection. In March 2002, as part of its 10-year inspection, the tank car was requalified as meeting the requirements of DOT specification 105J500W tank cars. Specifically, the shell thickness was inspected along with the attachment welds and stub sills. The tank was also pressure tested. Since its construction in 1976, the tank car has required only routine maintenance.

Hazardous Materials Information

Chlorine of the type released in this accident is shipped as a compressed liquefied gas. Chlorine is regulated by the DOT as a Division 2.3 gas that is poisonous by inhalation. Chlorine gas is greenish yellow with a pungent suffocating odor; it is about 2 1/2 times as heavy as air. If inhaled, chlorine will react with moisture in the respiratory tract and lungs to form hydrochloric acid, resulting in inflammation of these tissues. Severe exposure can

result in pulmonary edema, suffocation, and death. At atmospheric pressure, liquid chlorine will boil at about -30° F. Chlorine is an extremely acute toxic chemical with a National Institute of Occupational Safety and Health immediately dangerous to life and health (IDLH) concentration of 10 parts per million. Concentrations below the IDLH level should allow a worker to escape an exposure without permanent health effects.

Tests and Research

Sight-Distance Tests

Sight-distance tests were conducted at the site 2 days after the accident. Time and weather were comparable to those at the time of the accident. A single locomotive unit of the same type as that involved in the accident and headed in the same direction was used for the tests. The signal at MP 222 was set to display an *advance approach* indication, just as it was when the UP train approached it on the morning of the accident. The signal became visible and recognizable to the test train crew at 6,764 feet.

The next signal, at MP 223.35, which displayed an *approach* indication as it had on the day of the accident, was first visible and recognizable at 3,580 feet. The signal before the west end of the Macdona siding, which was displaying a *stop* indication, was in a $2^{\circ} 15'$ curve to the south. Because of the curve, this signal was first visible at 506 feet.

Tank Car Examination

After the accident, the car was transported from Macdona to the General Electric railcar repair facility, in Texarkana, Arkansas. On July 27, Safety Board investigators convened in Texarkana to survey the tank car. The punctured tank car had yellow urethane insulation installed between the shell and jacket. Samples of the yellow foam were collected for comparison with similar material found on the damaged corner of the flatcar that had been the 12th car in the UP train. Fourier transform infrared spectroscopy analysis showed that the spectra from the two materials were almost identical.

The portion of the breached tank that contained the puncture and dent was cut from the car for examination. When this excised head portion was placed against the deformed corner of the flatcar with the foam residue, the fold on the top surface of the flatcar fit snugly into the punctured portion of the head. The size of the puncture and inward deformation on the head were consistent with the shape and size of the damaged corner of the flatcar.

The thicknesses of the head and shell of the tank of the punctured tank car were measured at the Safety Board's Materials Laboratory. The thickness of the tank head in areas with no deformation damage measured between 0.813 and 0.830 inch, confirming that the thickness of the head was greater than the nominal thickness specified in the certificate of construction (0.8125 inch). The thickness of the wall at the fracture in the area that exhibited the most severe deformation measured approximately 0.5 inch. The deformation had

reduced the thickness of the head wall by 38 percent. The thickness of the tank shell measured between 0.783 and 0.793 inch, confirming that the thickness of the shell was greater than the nominal thickness specified in the certificate of construction (0.7751 inch).

Although the details of the fracture surface of the puncture were obliterated by exposure to chlorine and water, many portions of the fracture were on a slant plane, and the tank was severely deformed in the vicinity of the puncture. Such features are consistent with ductile failure. To gain more information about the fracture toughness and resistance to fracture of the tank head and tank shell, the Safety Board arranged to conduct Charpy tests on coupons from those areas.²⁵ The results of the Charpy tests indicated that the hot-formed tank head had properties similar to normalized steel,²⁶ with a ductile-to-brittle transition temperature of -40° F. The tests revealed that the steel in the tank shell had a ductile-to-brittle transition temperature greater than 85° F.²⁷ At 32° F (close to the loading temperature of the chlorine in the tank car), the energy absorbed by tank shell Charpy specimens oriented transversely to the rolling direction of the steel plate (the orientation with minimum fracture toughness) averaged 13 foot-pounds.

Signal Inspection

The traffic control system employed on the Del Rio Subdivision maintains a log of communication between the UP dispatch center and the wayside field equipment. Postaccident data were downloaded from these logs, and a timeline of relevant signal events was generated. The information from these logs showed that at the time of the accident, the wayside signals were displaying the proper signal sequence for train movements in either direction along the main line. The data logs of each of the relevant signals approaching the accident site were found to indicate codes that were in accordance with the displayed signal aspects. The lamp and the signal mechanism of the signal at the west end of the Macdona siding (which indicated *stop* at the time of the accident) were inspected and tested and found to function as designed.

The east and west ends of the Macdona siding were control points where train movements were governed by three wayside signals. At each point, a wayside signal governed trains approaching the siding switch from either direction along the main line. A third signal governed movements of trains coming out of the siding back onto the main line.

²⁵ *Charpy impact testing* consists of measuring the energy that notched specimens of a material will absorb before fracturing. Materials that absorb a greater amount of energy before fracture are considered to be more resistant to catastrophic failure. For a detailed description of Charpy impact testing, see appendix E to National Transportation Safety Board, *Derailment of Canadian Pacific Railway Freight Train 292-16 and Subsequent Release of Anhydrous Ammonia Near Minot, North Dakota, January 18, 2002*, Railroad Accident Report NTSB/RAR-04/01 (Washington, DC: NTSB, 2004).

²⁶ *Normalized steel* has undergone a heat treatment process that lowers the temperature at which the material transitions from ductile to brittle. The process also increases the amount of energy required to cause fracture at most temperatures. Since 1989, pressure tank car shells have been required to be fabricated from normalized steel.

²⁷ The ductile-to-brittle transition temperature indicated in this report is for transverse Charpy specimens.

The Macdona siding switches themselves were controlled remotely by the train dispatcher. Before lining one of the switches from the main line onto the siding or returning a switch to its “normal” (main line) position, all three signals at that control point display a *stop* indication.²⁸ After the switch has been relined and the control system has electronically verified that it is properly positioned, the dispatcher can request that the *stop* indications be cleared so that train operations can resume.

The investigation revealed that the day before the accident, June 27, 2004, a remedy ticket was entered into UP maintenance records for the control point signals at the east end of the Macdona siding. The ticket was for a track occupancy light, meaning that the track circuit was indicating occupied with no trains in the area. On three occasions, including Sunday, June 27, the train dispatcher could not clear those signals for train movements (that is, the signals continued to display *stop*) after the switch had been remotely lined for a train to leave the siding. On those occasions, a train crewmember checked to be sure the switch was properly lined and then flagged the train safely across the switch. After the train had left the siding, the crewmember manually returned the switch to its normal position and then reset it to be operated remotely. At that point, the dispatcher could clear the signals, and train operations returned to normal. The UP scheduled a signal maintainer to check the switch circuits on Monday, the day of the accident.

After the accident, it was determined that faulty electrical insulation on a switch rod was causing a “shunt” across the rails when the switch was thrown, as if the block of track were occupied by a train. The false occupancy indication prevented the dispatcher from displaying a permissive signal while the switch was set for the siding. No anomalies had been noted with east Macdona signals when the switch was in its normal alignment, as it was at the time of the accident.²⁹

The investigation determined that on the day of the accident there were no track occupancy indications in either direction that were not associated with train movements. The eastbound signal at the west end of the Macdona siding displayed a *diverging* indication for the eastbound BNSF train (which would be diverging from the main line into the siding) for approximately 1 hour 7 minutes. The main line switch at the east end of the siding remained lined for movements westbound on the main track. The westbound signal before the east end of the siding displayed an *approach* indication (for the UP train) for approximately 22 minutes.

Track Inspection

According to the UP, tracks on the Del Rio Subdivision are inspected 7 days a week during the summer because of the severe heat and the effects it can have on rail and track. The track supervisor for the Del Rio Subdivision stated that he had inspected the track between Withers (MP 218.84) and Uvalde Station (MP 301.0), which included the

²⁸ With these signals indicating *stop*, the intermediate signals automatically display *advance approach* and *approach* for trains nearing that location.

²⁹ Even though the BNSF train had been diverted into the west end of the siding, it was to remain there and was not intended to return to the main line until some time later.

accident area, on June 26, 2004. The assistant track foreman inspected the same segment of track the following day, June 27, 2004, which was the day before the accident. No abnormalities were found during either of these inspections. Because 20 switch ties of various lengths had been inserted into the switch at the west end of the Macdona siding, the foreman had placed a slow order in the switch area. The slow-order maximum speed had been increased on Saturday, June 26, to 45 mph, and it was to remain at this speed for 48 hours, at which time the slow order would be lifted, and the track would be returned to normal operating speed.

Mechanical Testing

After the accident, the cars that did not derail were moved from the scene for inspection. The non-derailed cars were inspected by UP car department personnel and FRA and Texas State inspectors. The inspection revealed 10 FRA defects on the lead block of cars on the BNSF train and 8 defects on the rear block of cars. The defects consisted of piston travel defects on the brake cylinders or non-response to brake applications. The non-derailed cars on the UP train had four similar FRA defects.

The UP train's lead locomotive alerter³⁰ was a Wabtec Railway Electronics-Pulse Electronics, Inc., Train Sentry, Part No. 17239P, manufactured December 31, 2001. At locomotive idle and at speeds up to and including 20 mph, the alerter will alarm if 2 minutes elapse without manipulation by the engineer. At speeds greater than 20 mph, the alerter alarm interval is 40 minutes (2,400 seconds) divided by the train's speed in mph. Thus, at 45 mph, the alarm interval is approximately 53 seconds. The alerter from the lead locomotive was tested and found to function as designed.

Some UP locomotives are equipped with video recorders that capture the view ahead of the train. Some of these devices are also capable of recording audio external to the train. The accident UP train lead locomotive unit was not equipped for video or external audio recording, and no locomotives are currently equipped with cab voice or video recorders.

Operating Rules and Crew Responsibilities

Both the UP and the BNSF subscribe to the *General Code of Operating Rules*, Fourth Edition, effective April 2, 2000. UP timetable System Special Instructions, effective April 1, 2004, also governed operations at the time of the accident.

³⁰ *Alerters* are devices intended to operate as a fatigue countermeasure. The alerter on a UP locomotive provides a visual and auditory alarm if the engineer does not make a control input (including sounding the horn) or otherwise physically respond to the control console within a set interval of time. This time interval decreases as locomotive speed increases, and each engineer action resets the device for the next interval. If the engineer does not respond to an alerter alarm, the train brakes will apply automatically.

General Code of Operating Rules Rule 1.47, “Duties of Trainmen and Enginemen,” states:

The conductor and the engineer are responsible for the safety and protection of their train and observance of the rules. If any conditions are not covered by the rules, they must take every precaution for protection.

According to the general operating rules, the conductor supervises the operation and administration of the train. All persons employed on the train must obey the conductor’s instructions, unless the instructions endanger the train’s safety or violate the rules. If any doubts arise concerning the authority for proceeding or safety, the conductor must consult with the engineer, who is equally responsible for the safety and proper handling of the train.

At the time of the accident, UP train conductors were required to record certain information regarding each trip on a Form 20849, Conductor’s Report. Instructions to conductors provided at the top of UP Form 20849 were as follows:

This report must be completed by the conductor of the road freight trains on each trip or tour of duty. Conductors must keep reports in their possession of the last 5 round trips, which must be presented to managers upon request. Report all signals more restrictive than clear (abbreviations may be used). Report all train defect detector (TDD) announcements. Report other train delays.

Information required on the form included:

All block signals that are more restrictive than Clear: Enter the block signal number (MP or [control point]), and the signal aspect.... Note in the comments section when the engineer has acknowledged the restrictive signal and after the crew members have discussed positive responses that will be taken to comply with that signal. A check mark or an ‘X’ may be used for this purpose.

The UP train conductor’s booklet of forms was found in the cab of the UP lead locomotive. The booklet contained completed 20849 forms for the conductor’s previous two trips but none for the accident trip.

General Code of Operating Rules Rule 1.17, addressing hours of service, states: “Employees are expected to use off-duty time so they are prepared for work.”

Delayed Release of UP Crews After Maximum Hours of Service

Crews reaching their federally mandated 12-hour service limits sometimes have to remain aboard their trains for extended periods awaiting transportation to an appropriate terminal. Depending on the distance to that terminal, a crew may then have to spend considerable time in transit before actually having the opportunity to obtain rest. This time spent awaiting transportation or in transit after the expiration of hours of service, referred to as “limbo time,” is not directly addressed in the hours-of-service regulations. Although

time spent in limbo is technically classified as neither on-duty nor off-duty time, it is paid time for the crew, and any required minimum rest period does not begin until the limbo period ends. As part of this accident investigation, the Safety Board examined records of the time spent in pay status by UP train crews on the San Antonio Service Unit and systemwide during the 6 months preceding the accident. Figure 5 shows the percentage of UP crew assignments held beyond 12 hours for the time periods indicated.

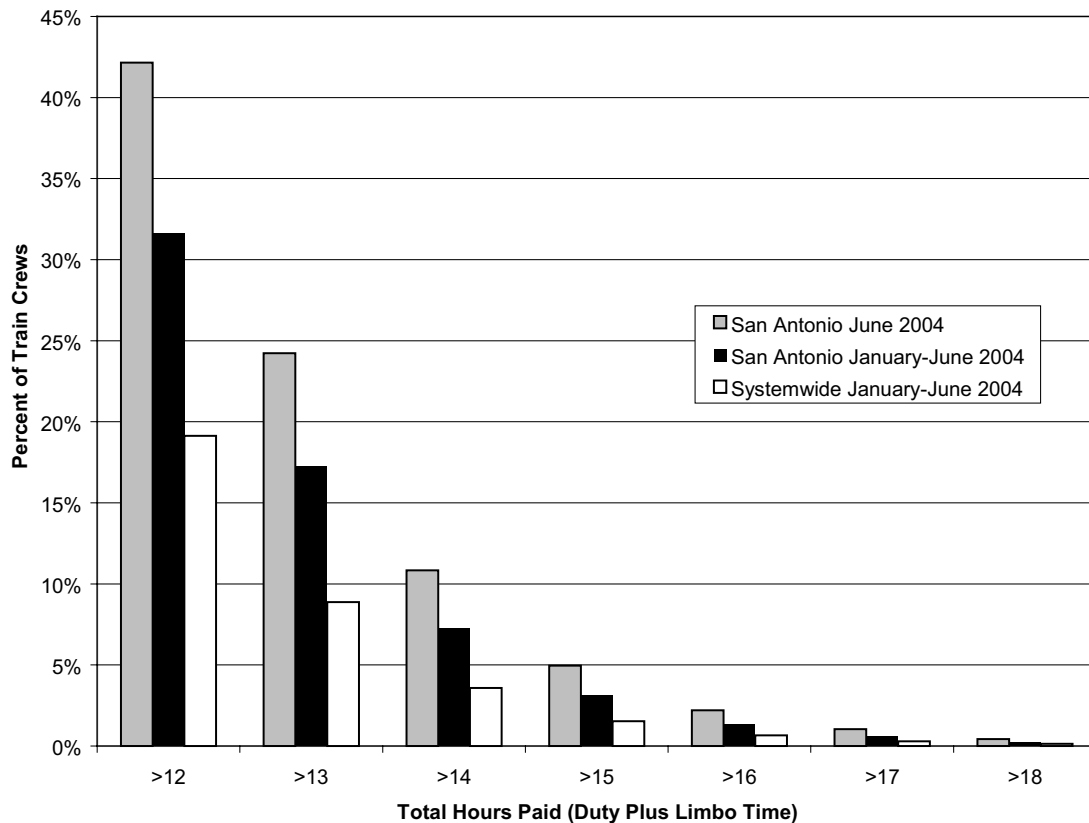


Figure 5. Percent of Union Pacific Railroad train crews working in extended pay status.

The UP also provided the limbo time information for the accident train crew. The number of times those crewmembers were held beyond 12 hours and the amount of time they were held is shown in tables 3 and 4.

Table 3. Number of times accident engineer held beyond 12 hours, January-June 2004.

Month	Total hours in pay status							
	>12	>13	>14	>15	>16	>17	>18	>19
January	9	1		1				
February	4							
March	5	2	1					
April	4			1	1			
May	1	4		2				
June	4	4				1		

Table 4. Number of times accident conductor held beyond 12 hours, January-June 2004.

	Total hours in pay status							
	>12	>13	>14	>15	>16	>17	>18	>19
January	1	3						
February		1						
March	6	2						
April	5				1			1
May	5	3		1				
June	5	3	2					

UP Fatigue Management

Fatigue Awareness Program

On July 2, 1997, near Delia, Kansas, a UP freight train that had been diverted onto a siding to await the passing of an opposing UP freight train instead continued through the siding and struck the side of the other train.³¹ The investigation revealed that the engineer of the striking train had dimmed the train's headlight but did not apply the train brakes even though the other train was sounding its horn repeatedly. The Safety Board determined that the engineer of the striking train was probably asleep. The engineer was fatally injured, and his conductor sustained minor injuries.

As a result of its investigation of the Delia, Kansas, accident, the Safety Board made several fatigue-related safety recommendations to the UP:

R-99-54

Issue to all employees, including management personnel, updated fatigue awareness material regarding shift work, work-rest schedules, and proper regimens of health, diet, and rest.

R-99-55

Revise your fatigue awareness program to include a process for documenting which employees receive the currently available fatigue awareness material, any new or updated fatigue-related information, or both, and for determining whether the recipients understand the dangers of working while fatigued.

³¹ National Transportation Safety Board, *Collision Between Union Pacific Freight Trains MKSNP-01 and ZSEME-29 Near Delia, Kansas, July 2, 1997*. Railroad Accident Report NTSB/RAR-99/04 (Washington, DC: NTSB, 1999).

R-99-56

Establish at a minimum, an annual management oversight review process for the fatigue awareness program to ensure its effectiveness and to identify ways of improving it.

R-99-57

In conjunction with the operating unions, discuss the circumstances of this accident with employees and advise them about the operating danger of working while fatigued.

In response to these safety recommendations, the UP identified various printed materials and videos that were issued to employees during training or safety meetings, distributed in routine employee mailings, or sent to employees upon request. The new materials and activities were described as follows:

- A book, *The Sleep Solution*, provided to new hires and regular employees
- Newsletter items prepared for *On Alert*, a UP newsletter
- A leader's manual developed for use during safety meetings
- Tips to employees made available at UP Online (a UP Internet site)
- Face-to-face alertness management training conducted during annual employee training classes
- Employee mailings containing information on scheduling, alertness management, and gaining family support
- Surveys mailed to employees to help them identify their health risk factors
- Alertness management subject matter delivered during UP's information and business television broadcasts to employees
- An 800 number employees can call for alertness management information
- Distribution centers that disseminate alertness management materials
- A series of fatigue-related brochures and videocassettes
- Health and safety fairs held for employees

On the basis of this and other information provided by the UP regarding its fatigue program, the Safety Board, on September 6, 2000, classified Safety Recommendations R-99-54 through -57 "Closed—Acceptable Action."

The Safety Board held a public hearing on March 20, 1998, and a followup hearing on February 24, 1999, regarding the Delia accident and a series of other UP accidents in which crew fatigue appeared to play a role. On April 26 and 27, 2005, during a public hearing about the Macdona accident, the UP's director of occupational health psychology was asked to update the Board on accomplishments in fatigue countermeasures since the earlier proceedings.

The director elaborated on multiple program activities addressing fatigue and stated that the UP had retained a series of consultants to advise the company on fatigue issues. The director stated that about 80 percent of his time was dedicated to fatigue and that he worked closely with other railroads to develop science-based pilot programs to reduce fatigue.

In addition to the distribution of fatigue-related written material and videos, the director discussed several other UP fatigue-related initiatives underway or planned:

- An agreement by which employees returning to work after more than 72 hours off would be shown available for work at 8:00 on the first day back instead of the traditional mark-up time of midnight; the change was made to help the employee readjust to shift work after having adapted to a normal work-sleep cycle
- An agreement to provide employees with 10 hours' uninterrupted rest at both home and away terminals
- Construction of crew away-terminal lodging specifically designed to facilitate rest (17 built and 7 planned at the time of the hearing)
- Information provided to new employees regarding the railroad's napping program³²
- Pilot projects to increase the accuracy of train lineup information to improve job assignment predictability
- Adjustment of employee boards (lists of qualified employees) to manage work and to balance mileage and work cycles among crews
- Ongoing study of potential fatigue avoidance and mitigation practices
- Workforce accretion

In response to a question about the programs that were in effect at the time of the 2004 accident, a UP official said that, although resources were inadequate to provide employees with classroom instruction in fatigue management and mitigation, all employees had received written information. Additionally, officials talked to managers about "managing fatigue, being alert, and helping the employees do the best they could as far as getting their rest." He also said:

We had a real aggressive hiring plan. We were working on recrew [relieving crews after maximum hours of service] reduction. We were vigorously working on the limbo time...to try to make ourselves more crews.... So we were working on three or four fairly significant initiatives as we were dealing with this sudden surge in business with varying degrees of success.

³² *General Code of Operating Rules* Rule 1.11.1 permits freight train crewmembers, under certain circumstances, to nap on their train for up to 45 minutes.

Fatigue Training for the UP Crew

According to the UP, the engineer received some version of fatigue management training during the new-hire training in 1998. Also, alertness management training was provided to him as part of required annual rules training on April 18, 2000. UP officials said the conductor received fatigue training on August 14, 2002, as part of his new-hire training. The conductor's training was presented in conjunction with a 1-hour videocassette, and he was required to complete a written homework assignment.

UP officials stated that written fatigue training materials are sometimes included with payroll documents mailed to employees' homes. Several employees told investigators that the information thus received is frequently treated as "junk mail" and discarded without being read.

The accident engineer said the company occasionally mailed safety-related material to employees. Although he did not recall whether he had received any mailings addressing fatigue, he said he remembered having seen a pamphlet "that [said] you should get eight hours' sleep [and] you should have a regular sleep cycle, which we don't have. [Also] it [said that when you sleep, the room] should be dark and quiet..." He also said, "The things that were in the pamphlet aren't things that we can do." The engineer said he had never been exposed to formal training of any kind having to do with alertness or fatigue. At the April 2005 public hearing on this accident, the director of occupational health said the company did not mandate periodic fatigue training for UP employees.

The UP, at the time of the accident, did not have a formal process by which employees could, without the risk of disciplinary action, decline a job assignment because of inadequate rest. UP officials said that the option existed for an employee to decline a job based on illness but that excess claims of illness, as with any pattern of being unavailable for work, could result in sanctions.

Other Information

UP Drug and Alcohol Testing Program

The FRA has established minimum annual testing rates for random drug and alcohol tests of railroad employees who perform covered service (that is, service subject to the hours-of-service laws). The FRA may increase or decrease those rates based on the reported positive rate for the entire industry.³³ The current FRA minimum annual testing rates are 25 percent for drugs and 10 percent for alcohol.

According to the FRA, the UP has elected to randomly test through-freight train crews at the following rates and times: The crews are randomly drug tested at a 50-percent rate annually, with the tests generally administered at the end of a run. About 25 percent of all crews are also tested for alcohol at the end of a run. The UP tests an additional 10 percent of the crews for alcohol at the beginning of a run.

³³ See 49 *Code of Federal Regulations* 219.602 and 219.608.

FRA Oversight of the UP

On November 10, 2004, the UP experienced an impact accident in San Antonio, Texas, during switching operations at a local industry. This accident followed previous UP train collisions in Carrizozo, New Mexico, on February 21, 2004, and in San Antonio, Texas, on May 3, 2004. A UP employee had also been killed during remote control operations in San Antonio on December 7, 2003. Each of these accidents involved the failure to adhere to UP operating rules or FRA regulations, or both.

In the aftermath of the Macdona accident, the FRA began, in July 2004, an extensive and comprehensive review of the UP's safety compliance performance in Texas. At the end of the review, the FRA found that the "UP had failed in its implementation and management oversight of its Field Testing Exercise Program, which tests train crew compliance with railroad operating rules and other Federal Safety Regulations, a result that was unsatisfactory." On November 16, 2004, the FRA used its authority under 49 *Code of Federal Regulations* (CFR) 209.201(b) to enter into a compliance agreement with the UP. The FRA's stated purpose for the compliance agreement was "to address deteriorating operating safety evidenced by the number of human factor accidents and incidents occurring on the UP in the San Antonio service area." The FRA stated that the UP's field testing exercise program "was not effectively providing a realistic evaluation of the level of employee compliance with operating and safety rules and Federal regulations."

The Safety Board examined FRA inspection data for calendar years 2003 and 2004, including the time period cited by the FRA in its justification of the compliance agreement with the UP. The data were examined to determine if the FRA had used enforced sanctions on the UP before it entered into the agreement that compelled the railroad to improve its field testing program and increase compliance with operating rules. Five defects were reported for the UP under 49 CFR Part 217 in 2003, and 20 were reported for 2004. No FRA violation reports were submitted during that period for non-compliance with Part 217.

Postaccident Actions of the UP

In response to the apparent failure of the crew of the accident UP train to comply with signal indications on the day of the Macdona accident, the UP formed a crew resource task team in San Antonio to address the issue of signal noncompliance. A procedure called the "Cab Red Zone" was developed to bring about improvement in cab operating discipline when encountering critical signal indications.

On February 5, 2005, the UP modified *General Code of Operating Rules* Rule 1.47, "Duties of Trainmen and Enginemen" as follows:

To ensure the train is operated safely and rules are observed, all crew members must act responsibly to prevent accidents or rule violations. A 'Cab Red Zone' (CRZ) exists during critical times when multiple tasks are occurring such as: Copying mandatory directives. Approaching temporary restrictions. Approaching the end of the trains authority [sic]. Operating at restricted speed except when switching. Or operating on signals more restrictive than Advance Approach or Diverging Advance Approach except when switching.

1. During 'CRZ', an environment must be created in the control compartment that focuses exclusively on controlling the train and complying with the rules. The conductor must be in the control compartment unless required by other duties to leave (i.e., to operate switches, be at a road crossing, passenger train duties, etc.). The following restrictions or conditions must be met:

- Cab communication is restricted to immediate responsibilities for train operation.
- Use of cell phones is prohibited unless train operations require their use.
- A crew member other than the employee operating the controls will be required to handle radio and/or cell phone communications when another crew member is in the control compartment....
- If proper action is not being taken, crew members must remind each other of the CRZ condition.

2. Crew members in the control compartment must communicate to each other any restrictions or other known conditions and required actions that affect the safe operation of their train sufficiently in advance of such condition to allow the engineer to take proper action.

If proper action is not being taken, crew members must remind the engineer of such condition and required action.

Crew members in the control compartment must be alert for signals. Crew members must:

- Communicate clearly to each other the name of signals affecting their train as soon as signals become visible or audible.
- Continue to observe signals and announce any change of aspect until the train passes the signal.
- Communicate clearly to each other the speed of the train as it passes a signal with an indication other than Clear.
- Immediately remind the engineer of the rule requirement if the signal is not complied with.

3. Except when switching, when a train passes a block signal with an indication more restrictive than Advance Approach or Diverging Advance Approach, a crew member must transmit by radio the engine number, direction, location and signal name....

4. If the engineer and/or conductor fail to comply with a signal indication or take proper action to comply with a restriction or rule, crew members must immediately take action to ensure safety, using the emergency brake valve to stop the train, if necessary.

Postaccident Actions of Emergency Response Agencies

Bexar County. Bexar County officials told the Safety Board that the county had taken the following steps as a result of the June 28, 2004, collision and derailment:

- All county sheriff's office fire alarm dispatchers and call takers have completed a course in hazardous materials awareness so that they might better understand recommended actions from the field such as shelter-in-place and evacuation procedures.
- A full-scale rail tank car exercise was conducted for the area fire departments.
- Area fire department personnel participated in incident command and unified command classes.
- Emergency notification procedures were revised to provide more efficient notification to residents. The procedures were tested during the full-scale rail tank car exercise.
- An initiative was undertaken to identify property locations accessible by a single roadway that could be blocked by a stopped train.

Southwest Volunteer Fire Department. The Southwest Volunteer Fire Department reported that it implemented a 15-point improvement plan after the accident. The improvements included railroad equipment familiarization as well as classroom and practical training that addressed responding to hazardous materials releases and working within an incident command and emergency operations management structure. The agency also rewrote its manual of standard operating procedures and guidelines to include detailed procedures for addressing railroad emergencies.

San Antonio Fire Department. Based on the "lessons learned" from the response to the Macdona accident, the San Antonio Fire Department took the following postaccident actions:

- A contingent of firefighters was provided with incident command system training, with chief officers and aides scheduled for enhanced incident system training. A multi-jurisdiction functional exercise was conducted in March 2005 with about 200 participants from different jurisdictions and disciplines. This exercise was preceded by a public information course, a tabletop exercise simulating a derailment with hazardous materials release, a 2 1/2-day incident command training class with tabletop exercise, and a workshop for senior officials.
- A mapping program was installed on the laptop computer in the department's incident command bus, and a large-format printer was acquired to facilitate the printing of maps.
- A mobile repeater system was acquired to improve radio communications.

- A regional command vehicle was ordered that would provide both command and communications integration to a large area and reduce mutual aid response problems.

UP Railroad. After the Macdona accident, the UP upgraded its mapping software to allow the overlay of UP track information on a separate layer of the mapping software. The company updated its telephone notification database and subscribed to quarterly updates of the Public Safety Answering Point data for Texas and the other States where the UP operates. The company also instituted advanced in-service training and testing protocols for all of its telephone operators.

Analysis

General

Under railroad operating rules, the conductor is responsible for supervising train operations and administration, whereas the engineer is primarily responsible for actually running the train. The crewmembers share responsibility for ensuring that all train movements are conducted safely. Both the engineer and conductor must observe signal indications, and both are equally responsible for ensuring that the train is operated in compliance with those indications. If the conductor observes that the engineer is not operating the train in compliance with the rules or is otherwise acting in an unsafe manner, he must remind the engineer of the requirements. If the engineer continues to disregard safety or rules considerations, the conductor is expected to take the actions necessary to remedy the situation, to include stopping the train. In this accident, neither the UP engineer nor conductor fulfilled his responsibilities.

The Accident

The accident UP train, for about the first 50 minutes of its trip, operated at speeds under 20 mph while it trailed a Laredo-bound UP freight train. After the Laredo train turned south, the accident train engineer, as would be expected, increased the throttle until the train was traveling at 49 mph, just under the maximum authorized speed over that track segment. Over the next few minutes, however, as the train approached the siding at Macdona, the engineer (and, by extension, the conductor) began to operate the train in a manner that was inconsistent with known operating conditions or UP rules.

For example, as the train approached and passed the *clear* signals at Withers and Alamo Junction, it traversed two grade crossings. The engineer did not sound the horn at either crossing, as required by UP operating rules. Then, after passing Alamo Junction at an appropriate speed of 46 mph, the engineer unaccountably slowed the train to 37 mph. He then used dynamic braking to slow the train even further as it neared the signal at MP 222, which was displaying an *advance approach* indication (because of the BNSF train nearing the Macdona siding). The train passed this signal at 22 mph. Had the train continued to operate at such a speed, the engineer would have been well positioned to comply with the *approach* signal displayed at the east end of the Macdona siding, which required that he proceed prepared to stop before the west end of the siding. (The engineer told investigators that he would normally be operating his train at no more than 10 mph if he were preparing to stop the train before the signal at the west end of the Macdona siding.) Instead, the engineer increased the train's speed, passing the *approach* signal at the east end of the Macdona siding at 46 mph. At that point, the UP train was only about 1 1/2 miles from the BNSF train, which was just entering the siding at its west end.

As the UP train passed over the east siding switch and began to parallel the siding, the train speed reduced slightly, to 44 mph, and the engineer made three short blasts of the horn. After sounding the horn, the engineer made one more control movement, reducing the throttle setting by one notch, but the train's speed remained at 44 mph. The engineer did not respond appropriately by dimming the headlight while passing the BNSF train on the siding, nor did he take any action when the *stop* signal at the west end of the siding came into view. The engineer continued to operate as if under *clear* signals up until the moment of impact with the 63rd car of the BNSF train.

The Safety Board therefore concludes that on the day of the accident, the crew of the accident UP train failed to operate their train in accordance with operating rules and in compliance with wayside signal indications, to include failing to take any action in response to the *stop* signal at the west end of the Macdona siding.

The Safety Board's investigation focused on the factors that might have caused or contributed to the UP crew's failure to operate their train as expected. The investigation also addressed the emergency response to the accident and the factors that contributed to the puncturing of a tank car and the fatal release of chlorine gas.

Exclusions

The accident occurred during darkness in clear weather. Signal visibility testing conducted after the accident revealed that the signals that were displaying *advance approach* and *approach* would have been visible and discernible from the locomotive cab of the UP train well in advance of its reaching the signals. The *stop* signal just before the west end of the Macdona siding would have been visible in time for the UP engineer to stop his train had he been proceeding in accordance with the *approach* signal he had passed just before reaching the east siding switch. At that point, it is also likely that he would have been able to see the cars of the BNSF train as that train was diverting into the siding.

Postaccident examination of data from the locomotive event recorders revealed no anomalies that would have contributed to noncompliance with operating rules or wayside signal indications. On the day before the accident, a problem was noted with the signals at the east end of the Macdona siding, but the investigation determined that the reported anomaly occurred only when the siding switch was lined for movements out of the siding; no signal problems had been noted when the switch was lined for the main line, as it was at the time of this accident. Further, the source of this anomaly (faulty insulation on a switch rod) had caused the signals to default to their most restrictive, thus safest, state. Finally, a review of signal data logs showed that all signal indications at the time of the accident were consistent with the sequence of train movements in both directions along the main line.

After the accident, the non-derailed cars from both the UP and the BNSF trains were inspected, and although some defects were noted, no defect was found that would

have significantly affected the operation of either train on the day of the accident. Track inspections in the area of the accident on the day before the accident revealed no abnormalities.

The investigation determined that both the UP engineer and conductor were adequately trained and qualified for their jobs and were sufficiently familiar with the territory over which they were working. Their medical records showed no health conditions that would have affected their ability to perform their work.

Postaccident toxicological tests for the UP and BNSF crews were negative for drugs. Although tests for alcohol were also negative for the UP engineer and the BNSF crew, the timing of the tests rendered the results inconclusive. There was, however, no evidence of alcohol use by the UP engineer or the BNSF crew in the hours before the accident.

Based on these findings, the Safety Board concludes that the following were neither causal nor contributory to the accident: weather conditions, signal operation, equipment performance, track condition, drug use, or crew training and qualifications.

UP Train Crew Work, Rest, and Fatigue

UP Engineer's Activities and Rest

The investigation determined that in June 2004, the UP engineer worked at least part of 22 days and that his time on duty ranged from 9 hours to more than 18 hours. Eleven of his work days were longer than 14 hours, with 1 day totaling 22 hours (12 hours on duty and 10 hours of paid limbo time). The engineer's schedule reflected several demanding periods of work, but they were offset by breaks from service. For example, he was off duty for 57 consecutive hours during the first week of June, 69 hours the next week, and 41 hours the third week.

The periods of on-duty and off-duty time for the engineer during the month of June would have put his circadian processes in a state of continuous readjustment. Based on the release-from-duty times shown on the engineer's work schedule, he would have had to obtain much of his post-work recuperative sleep primarily during the daytime. Research has determined that daytime sleep is typically shorter in duration and is degraded in quality as compared with nighttime sleep.³⁴ For the remainder of the month of June, the engineer's rest would have included nighttime sleep, either when he worked during the day, or when he had multiple-day breaks in service. Such frequent changes in work/sleep patterns have been shown to disrupt circadian rhythms in a way that can degrade work performance.³⁵

³⁴ A. J. Tilly, R. T. Wilkinson, P. S. G. Warren, B. Watson, and M. Drud, "The Sleep and Performance of Shift Workers," *Human Factors* Vol. 24, No. 6 (1982): 629-641.

³⁵ D. Kripke, M. Marler, and E. Calle, "Epidemiological Health Impact," in C. Kushida, ed., *Sleep Deprivation, Clinical Issues, Pharmacology, and Sleep Loss Effects* (New York: Marcel Dekker, 2005) 203.

A complicating factor in the case of the UP engineer was that he did not have a residence of his own. Because he was staying with a fellow engineer but spending all his waking hours elsewhere, he did not have the usual relaxation time preparatory to sleeping that would have contributed to his obtaining recuperative rest. The combined effects of intermittent day and night work and the obstacles the engineer faced in obtaining adequate rest because of his living arrangements likely led to his developing a cumulative sleep loss, or sleep *debt*. Sleep debt occurs when an individual does not obtain sufficient restorative sleep over time.³⁶ According to one prominent sleep researcher, the tendency of an individual to fall asleep increases progressively in direct proportion to the increase in the sleep debt.³⁷

In the 3 days immediately before the accident, the UP engineer engaged in an intense concentration of work followed by time spent in personal activities on Sunday. Work records show that he had only 9 3/4 hours off duty (after his tour) on Friday, June 25, and 9 1/2 hours off duty on Saturday, June 26. Based on his statements to investigators, he obtained only about 1 1/2 hours of bed rest (in addition to napping on a sofa while watching television) in a 31-hour period between his being called for work on Saturday evening, June 26, and the time of the accident. This lack of recuperative sleep would have increased the sleep debt the engineer was already experiencing because of his work schedule and living arrangements. Under these circumstances, the engineer would be expected to experience notably high sleep pressure with a resulting reduction in his ability to resist falling asleep.

The Safety Board therefore concludes that the UP engineer's combination of sleep debt, disrupted circadian processes, limited sleep through the weekend, and long duty tours in the days before the accident likely caused him to start the accident trip with a reduced capacity to resist involuntary sleep.

This is not to say that, despite his intense work schedule in the days before the accident, the engineer did not have ample time to obtain rest. Had he been determined to do so, the engineer could have obtained recuperative rest after his tours on Friday and Saturday before the accident. And with some effort, he could have obtained even more rest on the Sunday before the accident.

The Safety Board notes that when the engineer went off duty on Sunday, he requested 12 hours' uninterrupted rest. But when he left the work site, he did not return to his temporary residence to seek rest. Instead, he drove to the home of his estranged wife, where he intended to spend time with his daughter. He said that he did nap on the couch while watching television before his daughter arrived, but such napping would not be expected to fully ameliorate the effects of the engineer's sleep debt. Similarly, when the engineer left his wife and daughter at about 8:30 p.m., he could have gone back to where he was staying to go to bed. This would have given him several hours of additional sleep before his call to work. But instead of going home, he went to visit a friend and played cards for several hours.

³⁶ W.C. Dement, *The Sleepwatchers*, 2nd ed. (Menlo Park, CA: Nychthemeron Press, 1996).

³⁷ Dement, 1996.

The engineer said that he had expected to get more sleep because he did not believe he would be called to work until later on Monday morning. But the engineer was well aware of the unpredictability of work in pool service. As he acknowledged during the public hearing on this accident, "I could be 15 times out and miss calls because they rolled the board and put me first out." He made no calls to the voice response system on Sunday to get up-to-date information on his standing or on job vacancies, although he may have accessed this information through the UP Web site.

UP Conductor's Activities and Rest

A review of the conductor's schedule in the 10 days before the accident showed that he had had 4 days off followed by 6 consecutive work days leading up to the day of the accident. His duty times for the 6 work days would have allowed him to continue the nighttime sleep pattern that he probably had adhered to during the preceding 4 off days. The conductor's call for the accident trip shortly after midnight on June 28 therefore inverted the work/sleep cycle he had developed over the previous 10 days. Such a disruption would be expected to produce "severe effects" for sleepiness and performance.³⁸

On Saturday, June 26, after working until 10:50 p.m., the conductor had 26 hours off duty before reporting for the accident trip. His housemate said that the conductor had stayed up until about 4:00 a.m. Sunday morning and slept until about 1:00 p.m. Sunday afternoon. He was then active until some time after 9:00, when he returned from the home of a friend. Based on the statements of his housemate, the conductor apparently did not go to bed immediately after returning home. Thus, at the time the conductor was called for the accident train early Monday morning, he had had, at most, only a few hours of sleep in the previous 11 hours. This limited amount of sleep could have exacerbated the effects of the conductor's inverted work/sleep cycle and could have made it more difficult for him to remain alert in the hours before the accident.

Postmortem toxicological tests of the conductor were negative for drugs but positive for ethanol (alcohol). The alcohol concentrations were 0.013 percent in the blood, 0.051 percent in the urine, and 0.029 percent in the vitreous humor. Although the small concentrations of alcohol in the blood and urine could be explained as natural byproducts of decomposition, the finding of 0.029 percent alcohol in the vitreous humor offers evidence that the conductor had ingested alcohol before reporting for work.³⁹ This finding was consistent with the housemate's statement that the conductor may have consumed some quantity of beer after he returned from his friend's home.

³⁸ M. Rosekind, *et al.*, in National Transportation Safety Board consulting report "Analysis of Crew Fatigue Factors in AIA Guantanamo Bay Aviation Accident," pp. 3-4, referenced in National Transportation Safety Board, *Uncontrolled Collision with Terrain, American International Airways Flight 808, Douglas DC-8-61 N814CK, U.S. Naval Air Station Guantanamo Bay, Cuba, August 18, 1993*, Aviation Accident Report NTSB/AAR-94/04 (Washington, DC: NTSB, 1994).

³⁹ D. Canfield, T. Kupiec, and E. Huffine, "Postmortem Alcohol Production in Fatal Aircraft Accidents," *Journal of Forensic Sciences* July (1993): 914-917. Also D. and V. DiMaio, *Forensic Pathology* (Boca Raton, FL: CRC Press, 1993) 446-450.

The Safety Board does not consider the conductor's alcohol use, in and of itself, to be causal to this accident. However, alcohol has been shown to have a sedating effect after use or after the concentration of alcohol in the body has begun to decrease.⁴⁰ Thus, the Safety Board concludes that the UP conductor's lack of sufficient rest before reporting to work, the disruption to his previous work/rest pattern that resulted from his change in work schedule, and his alcohol consumption on the evening before the accident likely combined to reduce his capacity to remain awake and alert during the accident trip.

As with the UP accident engineer, the UP conductor could have made more effective use of his off time to obtain rest in view of the unpredictability of his work schedule. For example, when the conductor returned home, after 12 hours of work, about 10:30 p.m. on Saturday evening, June 26, he did not go to bed, even though this would have been in keeping with the nighttime sleep pattern he had developed over the preceding days. Instead, he stayed up watching movies until about 4:00 a.m. At that point, he would likely have been awake for 20 hours or more. He then slept, according to his housemate, for about 9 hours. While this sleep was certainly beneficial, its timing would make it difficult for him to obtain meaningful additional rest if he should be required to report for work late Sunday or, as it happened, early Monday.

The conductor was obviously concerned about the possibility that he would be called to work late Sunday or early Monday morning, as evidenced by his checking the UP Web site and his calls to the automated voice response system. But even though, according to his housemate, the conductor knew fairly early in the evening that he was "second or third out," he did not prepare for possible work by going to bed earlier on Sunday evening or by foregoing the use of alcohol. It is not known if the last call the conductor made to the voice response system alerted him to the possibility that he would be called before 1:00 a.m. on Monday morning. But even if he had been called somewhat later Monday morning, he would still have had to report to work after having received very little rest in the preceding 12 hours and while possibly feeling the sedating effects of alcohol.

The Safety Board therefore concludes that neither the engineer nor the conductor of the UP train made effective use of the time that was available to them, between the time they were released from their previous assignments and the time they were called for the accident trip, to obtain rest.

UP Crew Performance During the Accident Trip

As noted previously, the crew of the accident UP train failed to comply with successive wayside signals approaching the siding at Macdona and then did not make any attempt to stop their train when the stop *signal*, and even the BNSF train itself, came into view. The Board considered whether these failures could be explained by the fatigue that

⁴⁰ T. Roehrs and T. Roth, "Sleep, Sleepiness, and Alcohol Use," *Alcohol Research and Health* Vol. 25, No. 2 (2001): 101-109.

would have been affecting both crewmembers when they reported for work and during the first part of their trip.

During the UP train's brief accident trip, which started at a time when the crewmembers' circadian processes would have been declining to their lowest level, the operating conditions were not favorable for resisting impairment from fatigue. The trip began with following another train, which did not provide significant operating challenges because of the slow speed the train was maintaining. According to event recorder data, the train traveled below 20 mph for the first portion of the accident trip. The combination of monotonous train operation, predawn darkness, and low level of illumination inside the cab would be expected to lower the mental arousal of even a well-rested train crew.

The Engineer's Performance

Given the operating conditions that favored lowered resistance to sleep pressure, the most likely explanation for the UP train's anomalous speed reduction after passing the *clear* signal at Alamo Junction was that the engineer experienced several moments of microsleep,⁴¹ or perhaps a brief period of mental confusion, as he approached and passed the signal (and as he proceeded over grade crossings without sounding the horn). Sensing a discontinuity in his cognitive awareness, the engineer may have begun slowing the train until he could reorient himself. He might not have remembered passing the *clear* signal, and a lower speed would have made it easier for him to comply if the next signal were restrictive.

Once the train passed the *advance approach* signal at 22 mph, the engineer once again began to operate his train inappropriately. Although the engineer's throttle and horn manipulations prevented an alerter alarm and show that he was not completely incapacitated by sleep, he was clearly not responding in a way that was consistent with his operating environment. He passed the signal at the east end of the Macdona siding as if it indicated *clear*. He continued to make minor throttle adjustments and to sound the horn, but his failure to dim his headlight when he passed the head end of the BNSF train on the adjacent siding track indicates that he probably was not aware of its presence.

Had the engineer been awake and alert when the two trains met, even if he had been sleeping earlier, he would have realized that a moving train on the siding meant that the track ahead may be fouled. That should have triggered a reduction in throttle and application of brakes to slow the train. Based on speed and distance calculations, the head ends of the two trains passed about 30 seconds before the collision. After the *stop* signal at the west end of the siding came into view, the engineer still had 7 seconds to place the brakes in emergency and at least mitigate the severity of the inevitable collision. Yet, the engineer took no action in response to the available stimuli.

That the engineer could have remained sufficiently alert to make train control inputs and yet be unable to respond to vitally important signal indications may be

⁴¹ *Microsleeps* are brief intrusions of sleep lasting for several seconds that are indicative of restricted sleep. Research suggests likely impairment to performance both before and after periods of microsleep.

explained by the fact that making such inputs and manipulating the alerter are highly practiced, nearly reflexive, motor responses that require only lower level cognitive effort. During the engineer's transition from wakefulness into the normal perceptual disengagement of unintended sleep, his capacity for information processing would have been severely compromised. Thus, he could have been able to continue the reflexive control activities while being unable to perform the higher level cognitive tasks of extrapolating information from the signal indications.

In summary, the engineer appears to have been progressively impaired by fatigue such that within 45 to 50 minutes of starting the accident trip, he was unable to resist the pressure to sleep. He likely experienced at least one brief intrusion of sleep while passing Alamo Junction, after which he made a precautionary reduction in speed until he could orient himself. He temporarily roused himself as he passed the *advance approach* signal, but in the minutes that followed, he likely experienced a deeper descent into sleep, from which he would not awaken until the collision and derailment. The Safety Board therefore concludes that the engineer of the UP train likely experienced one or more periods of microsleep early in the accident trip, and these were probably followed by a deeper descent into sleep as the train traveled past the signal at the east end of the Macdona siding.

The Conductor's Performance

The fact that the train was not operated in compliance with signal indications and operating rules before reaching the Macdona siding offers evidence that neither crewmember was consistently attentive to his work during the accident trip. Even if the engineer had been experiencing microsleeps, an alert conductor would have monitored the engineer's performance and prompted him as necessary to ensure that the train was operated safely. Not only was this not done, but the conductor also did not make the required entries on the conductor's report, Form 20849. Before reaching Macdona, the train passed several signals more restrictive than *clear*, each of which should have been noted on the form. The conductor should also have indicated on the form that he and the engineer had discussed the responses necessary to comply with restrictive signal indications. None of this information had been entered on the conductor's report for the accident trip. Finally, the engineer stated that after the collision, the conductor asked him what had happened. This indicates that the conductor had not been awake and observant for some period of time leading up to the collision. The Safety Board therefore concludes that the conductor of the UP train was most likely asleep during much of the accident trip.

The Safety Board further believes that the UP should use the Macdona collision as a case study in fatigue awareness training to illustrate the shared responsibilities of the carrier to provide an employee the opportunity for adequate sleep and of the employee to acquire sleep sufficient to work at a safe level of alertness, and the options available if adequate sleep is not obtained. Because the responsibility for avoiding crewmember fatigue is shared by the carrier and the crewmember, the Safety Board believes that the Brotherhood of Locomotive Engineers and Trainmen (BLET) and the United Transportation Union (UTU) should also use this accident as a fatigue case study to illustrate the responsibility of the carrier to provide an employee the opportunity for

adequate sleep and the responsibility of the employee to acquire sleep sufficient to work at a safe level of alertness, and the options available if adequate sleep is not obtained. The BLET and the UTU also should present this case study to their members at meetings, through written materials, and other appropriate methods.

Emergency Response

The initial accident notification to response agencies was via a 911 call that was made within about 3 minutes of the accident from a residence several hundred feet from the accident site. Within minutes, emergency responders from the Southwest Volunteer Fire Department were en route to the scene, responding to what they believed was a routine medical emergency involving smoke in a residence. They were not aware of the true nature of the incident.

Once aware that the emergency involved a chlorine gas release, fire department responders withdrew and requested mutual aid from surrounding jurisdictions. Some of the firefighters also donned personal protective gear and began a search of the area. Within about the next hour, additional emergency response resources arrived, and incident command was being established to coordinate and direct the response.

The proximity to the accident site of the residences near the Nelson Road grade crossing placed the occupants of those residences in immediate peril. While the occupants of the residences on the north side of the main line track were able to exit the area via Nelson Road or through the nearby open fields, those in the two residences south of the grade crossing were unable to escape the chlorine gas cloud. Occupants of one residence made 911 calls to report the situation at their location and to urgently request help, and although on-scene responders were subsequently made aware of these calls, rescue efforts on behalf of the endangered residents did not commence for more than 3 hours after the collision.

The rescue effort was seriously impeded by the limited vehicular access to the affected residences. The general topography of the area, the muddy conditions of the agricultural fields near the houses, the flooded Medina River, and the blocked Nelson Road grade crossing all prevented rescue vehicles from accessing the residences and aiding the victims. Since the accident, the Bexar County Emergency Management Division has undertaken a review of property locations where access could be blocked by a stopped train so that alternative emergency access routes can be identified in advance of an actual emergency.

Based on the postaccident emergency debriefings and interviews with responders, no consideration was given to using the open farm fields to the south of the accident site as potential helicopter landing areas or drop sites for firefighters. Responders also did not consider accessing Nelson Road south of the crossing via the unpaved and muddy roadways to the south of the accident site. Accordingly, the investigation determined that, although impassible to vehicle traffic, the open farm fields to the south of the accident site

afforded potential helicopter landing sites or firefighter drop-off sites that were sufficiently far from the accident site to avoid the chlorine gas hazard. Further, the unpaved roadways south of the accident site (which provided access to the open farm fields), although too wet for vehicle traffic, could have allowed firefighters traveling on foot to reach the two occupied residences. The failure of the emergency response agencies to consider these alternative response and rescue tactics suggests that incident command for the accident remained too focused on non-critical elements of the event and was not examining unconventional response/rescue tactics to gain access to the two threatened residences.

The delay in the search and rescue efforts reflects the lack of immediate, concentrated, focused efforts to reach those who were in the most danger. Apparently, each of the responding agencies followed its own course of action and did not effectively function as a part of a mutually supporting, unified entity. The Safety Board therefore concludes that, even though the initial dispatch of emergency response resources to the accident was timely, the overall execution of the incident command process during the response effort was not timely, effective, or appropriate.

In response to the deficiencies noted in this investigation and during postaccident reviews, a series of training initiatives (for example, incident command classes, participation in multi-jurisdiction functional exercises, and revisions of emergency response protocols) were undertaken by the emergency services agencies of Bexar County to help prevent a recurrence of the problems that were experienced in this incident.

Tank Car Performance

A flatcar loaded with steel plates was positioned four cars ahead of the punctured chlorine tank car in the accident train. During the derailment, this car came to rest adjacent to the derailed and punctured chlorine tank car (the 16th car in the train). When the damaged corner of the flatcar was positioned against the punctured car, it was found to match the shape of the indentation in the tank car head. Further, the corner of the flatcar also contained shards of urethane that matched the insulation from the chlorine tank car. The Safety Board therefore concludes that the chlorine tank car that released a portion of its load in this accident was punctured during the derailment by impact with the left side frame member of the flatcar loaded with steel plates that was four cars ahead of the chlorine car in the train.

The speed of the train at the time of the collision was about 44 mph. Consequently, the punctured tank head of the chlorine car was subjected to severe derailment loading forces from its impact with the flatcar. Despite the magnitude of these forces, the puncture was relatively small and did not result in a catastrophic failure of the tank. Still, an estimated 9,400 gallons (60 tons), or two-thirds of the liquefied chlorine in the tank car, were released.

The DOT hazardous materials regulations, at 49 CFR 179.16, contain performance standards for tank head puncture resistance. The performance standards require that a tank head puncture-resistance system be adequate to permit the tank head to sustain, without any loss of lading, coupler-to-tank-head impacts at relative car speeds of 18 mph. The intent of this standard was to reduce or eliminate head punctures to loaded tank cars caused by over-speed impacts during coupling operations in railroad yards.⁴²

In 1995, the hazardous materials regulations⁴³ were amended to require tank head puncture-resistance systems for the entire tank head on pressure tank cars. The Research and Special Programs Administration acknowledged in the 1995 rulemaking that:

Analysis of data on main-line accidents showed that objects, such as broken rails and couplers, may penetrate the top half of the tank head, indicating that head protection is essential, even though not 100 percent effective, in a train derailment.

Although the punctured tank car did not have separate head shields, the protection afforded by the steel jacket, insulation, and enhanced tank head thickness met the performance standard of 49 CFR 179.16 for a tank head puncture-resistance system.

The Safety Board's Materials Laboratory determined that the fracture features of the puncture surfaces were consistent with a shear failure. The laboratory also found that the head material directly adjacent to the puncture was severely deformed consistent with a ductile deformation.

Charpy tests on coupons from the punctured tank head and from the tank shell indicated that the hot-formed tank head had properties similar to normalized steel, with a ductile-to-brittle transition temperature of -40°F , which is considerably below the loading temperature of 30°F for the chlorine. The steel in the tank head was therefore ductile at the time of the derailment, and this ductility was a significant factor in limiting the size of the puncture. In contrast, the steel in the tank shell was not subjected to a normalizing heat treatment and had a ductile-to-brittle transition temperature greater than 85°F , indicating that the tank shell material would have been brittle under most operating conditions. Also, at 32°F (close to the loading temperature of the chlorine in the tank car), the energy absorbed by tank shell Charpy specimens oriented transversely to the rolling direction of the steel plate (the orientation with minimum fracture toughness) averaged 13 foot-pounds, which is lower than the corresponding Charpy impact energies for some of the catastrophically fractured tank car shells in the Minot, North Dakota, accident. The lower Charpy impact energy indicates that the fracture toughness of the steel from the shell of

⁴² As early as 1978, the Safety Board recommended the installation of head shields on pressure tank cars to protect tank heads from punctures occurring in derailments and other accidents. Between 1978 and 1991, the Board issued several safety recommendations calling for head shield protection on all pressure tank cars transporting any regulated liquefied gas and on tank cars transporting other designated hazardous materials.

⁴³ "Crashworthiness Protection Requirements for Tank Cars; Detection and Repair of Cracks, Pits, Corrosion, Lining Flaws, Thermal Protection Flaws and Other Defects on Tank Car Tanks," 49048 *Federal Register* Vol. 60, No. 183 (September 21, 1995).

the Macdona tank car was inferior to that of some of the steels from the tank cars ruptured in the 2002 derailment in Minot (discussed in more detail below). However, the structural differences between the Macdona tank car and the Minot tank cars would determine the loading conditions under which any of these tank cars would catastrophically fail. Nevertheless, the Safety Board concludes that the shell of the punctured chlorine tank car in this accident would have been susceptible to catastrophic fracture if it had experienced a large penetration of several feet or more.

Previous Safety Board Actions Regarding Tank Cars

Because the punctured chlorine tank car was built before 1989, only the tank heads were required to be constructed of normalized steel;⁴⁴ the tank shell was constructed of non-normalized steel. The Safety Board previously addressed the problems with the pre-1989 pressure tank cars in its investigation of the January 18, 2002, derailment in Minot, North Dakota.⁴⁵ The Board most recently addressed the transportation of chlorine and other poisonous-by-inhalation gases in its investigation of the collision of two freight trains in Graniteville, South Carolina, on January 6, 2005.⁴⁶

Minot

In the Minot accident, five fully loaded DOT class 105 tank cars sustained catastrophic shell failures and instantaneously released about 146,700 gallons of anhydrous ammonia. Sections of the fractured tanks were propelled as far as 1,200 feet. The tank shells of four of the five tank cars were brittle and thereby had reduced fracture toughness properties. The steel of the fifth tank car, although ductile, also had very low fracture toughness properties. The Safety Board concluded that the low fracture toughness of the non-normalized steels used for the tank shells of the five tank cars that catastrophically failed contributed to the cars' complete fracture and separation.

As a result of the Minot investigation, the Safety Board, on March 15, 2005, issued the following safety recommendations to the FRA:

⁴⁴ During the hot forming process, the tank heads were subjected to normalizing temperatures used to shape the heads.

⁴⁵ National Transportation Safety Board, *Derailment of Canadian Pacific Railway Freight Train 292-16 and Subsequent Release of Anhydrous Ammonia Near Minot, North Dakota, January 18, 2002*. Railroad Accident Report NTSB/RAR-04/01 (Washington, DC: NTSB, 2004).

⁴⁶ National Transportation Safety Board, *Collision of Norfolk Southern Freight Train 192 With Standing Norfolk Southern Local Train P22 With Subsequent Hazardous Materials Release at Graniteville, South Carolina, January 6, 2005*. Railroad Accident Report NTSB/RAR-05/04 (Washington, DC: NTSB, 2005).

R-04-4

Conduct a comprehensive analysis to determine the impact resistance of the steels in the shells of pressure tank cars constructed before 1989. At a minimum, the safety analysis should include the results of dynamic fracture toughness tests and/or the results of nondestructive testing techniques that provide information on material ductility and fracture toughness. The data should come from samples of steel from the tank shells from original manufacturing or from a statistically representative sampling of the shells of the pre-1989 pressure tank car fleet.

R-04-5

Based on the results of the Federal Railroad Administration's comprehensive analysis to determine the impact resistance of the steels in the shells of pressure tank cars constructed before 1989, as addressed in Safety Recommendation R-04-4, establish a program to rank those cars according to their risk of catastrophic fracture and separation and implement measures to eliminate or mitigate this risk. This ranking should take into consideration operating temperatures, pressures, and maximum train speeds.

R-04-6

Validate the predictive model the Federal Railroad Administration is developing to quantify the maximum dynamic forces acting on railroad tank cars under accident conditions.

R-04-7

Develop and implement tank car design-specific fracture toughness standards, such as a minimum average Charpy value, for steels and other materials of construction for pressure tank cars used for the transportation of U.S. Department of Transportation class 2 hazardous materials, including those in "low-temperature" service. The performance criteria must apply to the material orientation with the minimum impact resistance and take into account the entire range of operating temperatures of the tank car.

In its initial response on August 9, 2004, the FRA described the actions being taken to address each recommendation. The FRA subsequently provided updated information on actions taken to implement these recommendations in correspondence dated December 15, 2005, and in meetings and conference calls held in April and May 2006.

Safety Recommendations R-04-4 and -5. In its initial response on August 9, 2004, the FRA stated that a task force under the Tank Car Committee of the Association of American Railroads (AAR) had developed a plan to sample steels from pre-1989 pressure cars as part of a risk assessment to evaluate the appropriateness of placing operating restrictions on tank cars. The task force proposed that steel sample coupons would be gathered only from the pre-1989 pressure tank cars as they were scrapped or retired; samples would not be taken from tank cars remaining in service.

On June 22, 2005, the Safety Board responded that the FRA's approach to Safety Recommendation R-04-4 did not appear to be random and did not include the representative sampling of all steel manufacturers and mill sites, tank car manufacturers, the range of steel plate thickness, dates of manufacture, product service, etc. The Board added that in order for the sampling to be comprehensive, the program should also consider the total number of tank cars to be sampled along with which groups of tank cars are to be sampled. Because the FRA's proposed actions did not ensure that the analysis would be completed in a timely manner or demonstrate the urgency that the Board believes is necessary, Safety Recommendation R-04-4 was classified "Open—Unacceptable Response."

In addressing the FRA's response to Safety Recommendation R-04-5, the Safety Board requested a more detailed description of how and when the ranking process would be conducted. The Board added that because of the FRA's commitment to ranking the pre-1989 fleet and implementing measures to mitigate the risk of the pre-1989 fleet, the Board classified Safety Recommendation R-04-5 "Open—Acceptable Response."

On December 15, 2005, the FRA again responded to Safety Recommendation R-04-4. The FRA stated that it continues to pursue data gathered from steel samples collected from scrapped tank cars; however, the FRA did not provide any further details on the number of tank cars to be sampled and the methodology for testing and analysis of the data. The FRA also added that the Universal Machine Language Equipment Register (UMLER) database has provided useful statistical information on the pre-1989 pressure tank car fleet in terms of year of manufacture and type of steel. This information will be used to compare the actual cars that failed in Minot and with previous work done by the industry's Tank Car Safety Test and Research Project about steels used in pre-1989 cars. The FRA also stated that it would implement Safety Recommendation R-04-5 when the work under Safety Recommendation R-04-4 was complete.

Seeking further clarification, Safety Board staff met with FRA staff on April 4, 2006. In regard to Safety Recommendation R-04-4, the FRA indicated that the AAR Tank Car Committee task force, in conjunction with the FRA, is currently studying the UMLER files to accurately determine the statistical distribution of pre-1989 pressure tank cars and the means for collecting representative samples. Testing of the samples has commenced to determine the mechanical and chemical properties, including dynamic fracture toughness, of the steel samples. The FRA reiterated that steel samples would be taken from tank cars as they were retired from service. As of February 2006, test samples from more than 24 tank cars have been collected and tested. The FRA noted that, at present, in order to obtain a complete picture, candidate material samples, especially TC-128B from tank cars manufactured between 1978 and 1989, are being sought.

Further, the data available through the UMLER files for an individual tank car include only the tank car manufacturer, the year of manufacture, and the grade of steel used to construct it. According to the FRA, specific information about the steel plate, such as the steel manufacturer, identification of the producing mill, rolling processes, and lot number of the steel plates, does not exist and is not available. The absence of such information makes it impossible to determine if steel from a specific supplier was of lower

fracture toughness than steel from other suppliers. Given that the UMLER data provide the specified grade of steel, the tank car manufacturer, and the year of manufacture, any representative sampling of steel from the pre-1998 tank cars would be limited to consideration of these three parameters. The limitation of parameters should simplify and reduce the number of test samples needed to obtain a representative sampling of the pre-1989 pressure car fleet. However, the Safety Board remains concerned that a representative sampling will not be obtained under the present sampling plan and asks that the FRA explain how it will conduct and complete a representative sampling based on accepted and proven principles of statistical analysis.

On April 7, 2006, the Safety Board obtained preliminary information on the testing program from representatives of Southwest Research Institute (Southwest), the FRA contractor performing the fracture toughness and Charpy tests on the samples from the pre-1989 tank cars. Southwest representatives indicated that a major emphasis of the testing program is on a fracture mechanics-based approach, because this approach traditionally can be applied to design parameters in mechanical structures. Also, the testing program is being conducted with a predetermined rate of loading. Southwest acknowledged that accident conditions, such as the rate and magnitude of loading, were not known but that the predetermined conditions in the testing program provided a starting point for collecting data on tank car steels. In the preliminary data reviewed by the Board, Southwest classified the fracture toughness of most of the steels tested so far (including steel from the Minot tank cars) as generally in the “acceptable” range, despite, as demonstrated by the Minot accident, the possibility that tank car shells made from this steel can catastrophically fracture in accident conditions. The Board notes that of the 12 stress intensity factor values generated at 0° F by Southwest for non-normalized TC128B steel samples taken from the Minot tank cars that catastrophically failed, five had toughness values at or above the toughness value reported by the National Institute of Standards and Technology (NIST) for normalized TC128B steel.⁴⁷ In contrast, the Charpy impact data in the NIST report is consistent with Safety Board and literature data, which indicate that the non-normalized steels generally exhibit much lower Charpy impact energies than the normalized steels. Possible contradictory results such as these should be clearly explained and justified before they can be accepted, independent of sampling issues.

During a visit to Southwest on May 22, 2006, Safety Board staff discussed the preliminary test data in more detail with representatives of the FRA, the Volpe National Transportation Systems Center, and Southwest engineers. Board staff noted that the preliminary fracture toughness data from the Southwest tests show a large variation in fracture toughness among the samples of steel plate tested, with no discernible trends correlating with the year of tank car construction or tank car manufacturer. Because of these variations, the sampling of steel from retired tank cars should be continued to ensure that no trends in the data are being missed due to the limited size of the pre-1989 tank car fleet available for testing.

⁴⁷ NIST report *NISTIR 4660, Mechanical Properties and Fracture Toughness of AAR TC128 Grade B Steel in the Normalized and Normalized and Stress Relieved Conditions*, September 1991.

Additionally, in one case, a large variation in toughness was measured for samples taken from the same plate. While the level of variance in the data may be representative of what should be expected fleet wide, the possibility of a large variation within an individual tank car has significant implications for the risk assessment called for by Safety Recommendation R-04-5. In order to assess whether this degree of variability is common within a single steel plate, the FRA is encouraged to complete additional sampling through Southwest to generate a representative database of fracture toughness for multiple material samples taken from a single tank car at a fixed temperature, preferably 0° F, and a fixed loading rate, or statically.

The low fracture toughness of the steel in the tank shell of the chlorine tank car in Macdona reinforces the need to complete action on Safety Recommendation R-04-4. Although the Safety Board still has questions about the interpretation and meaning of the sampled fracture toughness data collected to date, as noted above, the Board believes that the FRA is making positive progress on addressing Safety Recommendation R-04-4, which is reclassified “Open—Acceptable Response” in this report. Because of the FRA’s commitment to implementing Safety Recommendation R-04-5 upon completion of work under Safety Recommendation R-04-4, Safety Recommendation R-04-5 remains classified “Open—Acceptable Response.”

Safety Recommendations R-04-6 and -7. In its initial response to Safety Recommendation R-04-6, the FRA stated, on August 9, 2004, that it had identified ongoing programs at the Volpe National Transportation Systems Center and the University of Illinois at Chicago to evaluate in-train forces associated with train derailments. The FRA anticipated that the modeling program would be completed in early 2006. On June 22, 2005, the Safety Board acknowledged that programs to analyze in-train forces had been identified. The Board also expressed its expectation that validation of the models was to be a standard part of any model development. Based on the FRA’s response, Safety Recommendation R-04-6 was classified “Open—Acceptable Response.”

The FRA stated in its initial response to Safety Recommendation R-04-7 that further research was required, which may necessitate a “3-year effort” to develop adequate tank car design-specific fracture toughness standards. In its June 22, 2005, response, the Safety Board stated that tank car design-specific fracture standards, such as Charpy impact values, can be achieved for standard manufacturing processes without waiting for the results of the modeling effort associated with Safety Recommendation R-04-6. The Board added that evaluation and analysis of the dynamics of the Minot accident can provide data about the levels of fracture toughness that may be necessary for pressure tank cars and that data from subsequent accidents in Macdona, Texas, and Graniteville, South Carolina, will provide additional information. Based on the FRA’s response, Safety Recommendation R-04-7 was classified “Open—Unacceptable Response.”

On June 24, 2005, the AAR, in collaboration with the FRA, revised its *Manual of Standards and Recommended Practices—Specifications for Tank Cars*. Under this revision, the steel plate used in the construction of pressure tank cars ordered after July 1, 2005, must meet Charpy impact testing standards for the orientation transverse to the rolling direction of the steel plate, the orientation that has the weakest impact resistance. The

Charpy test coupons must simulate the in-service condition of the material and must meet the minimum requirement of a 15 foot-pound average for three specimens, with no single value below 10 foot-pounds and no two below 15 foot-pounds at -30°F .

The AAR's new standards ensure that a minimum level of impact resistance for normalized steel can be verified by a standardized testing method. The new standards also require that the Charpy tests be performed in the orientation of the sample material with the lowest impact property. With the implementation of these new standards, the emphasis is placed, properly, on fracture toughness properties rather than solely on normalization of the steel plate. The Safety Board considers the implementation of the AAR standards to be a first step in a process of developing a fracture toughness standard for steel in pressure tank cars.

The process of developing meaningful fracture toughness standards that will be refined and updated as new steels are developed will be linked to the development and refinement of predictive models of forces occurring in rail accidents. As noted previously, the FRA is sponsoring ongoing programs at the Volpe National Transportation Systems Center and the University of Illinois at Chicago to evaluate in-train forces associated with train derailments. Missing from these programs is a structural mechanics approach to translate car forces to stress and deformation states in tank car structures. It is this level of knowledge that enables the driving forces for crack growth and propagation to be defined, an essential step if a fracture toughness requirement is to be quantified. In the view of the Safety Board, the fracture toughness requirements for tank cars should be reevaluated and adjusted as information from research/modeling on impact dynamics and structural response becomes available. Such an approach would help lay the foundation for the future design of tank cars with greater puncture resistance and penetration resistance.

As demonstrated by the accidents in Graniteville, South Carolina, and in Macdona, punctures in chlorine tank cars with the release of the chlorine gas can be catastrophic, even if the operating stresses on the tank are too low to cause the catastrophic growth of the cracks generated by the penetration process. Consequently, the Safety Board considers a "design-specific fracture toughness standard" as specified in Safety Recommendation R-04-7 to include, in addition to a consideration of the lethality of the tank car contents, a structural level penetration and crack growth assessment. The Board believes that the data being developed at Southwest, particularly on the variability of the fracture toughness of the test samples, can also be used to advance Safety Recommendations R-04-6 and -7. The Board encourages the FRA to address these points in the modeling work underway at the Volpe National Transportation Systems Center and the University of Illinois at Chicago. Because it appears that the FRA is making progress on the modeling of accident forces and the development of fracture toughness standards, Safety Recommendation R-04-6 remains classified "Open—Acceptable Response," and Safety Recommendation R-04-7 is reclassified "Open—Acceptable Response."

Because the Safety Board is convinced that the successful and timely completion of all four of the above safety recommendations is of critical importance to improving the safety of pressure tank cars and the protection of the public, the Safety Board reiterates Safety Recommendations R-04-4 through -7 to the FRA.

Graniteville

The Safety Board also investigated the January 6, 2005, collision and derailment in Graniteville, South Carolina, that resulted in a puncture in the shell of a chlorine tank car. Nine people died due to exposure to the chlorine gas. The Board concluded that even the strongest tank cars in service can be punctured in accidents involving trains operating at moderate speeds. As a result of the Graniteville investigation, the Board on December 12, 2005, issued the following safety recommendation to the FRA:

R-05-16

Require railroads to implement operating measures, such as positioning tank cars toward the rear of trains and reducing speeds through populated areas, to minimize impact forces from accidents and reduce the vulnerability of tank cars transporting chlorine, anhydrous ammonia, and other liquefied gases designated as poisonous by inhalation.

On the afternoon of July 3, 2006, the FRA provided the Safety Board with an advance copy of its June 30, 2006, letter responding to Safety Recommendation R-05-16. The letter notes that the FRA does not believe that placing tank cars filled with poisonous by inhalation cargo at the rear of trains would be prudent. Further, the FRA's letter notes that despite the fact that catastrophic releases are very rare events and practical impediments to speed restrictions are substantial, it will review the potential benefits and costs of slowing trains carrying certain toxic commodities. The Board considers the failure of the FRA to respond to the December 12, 2005, safety recommendation in a timely manner to be unacceptable. Pending further evaluation of the information provided, Safety Recommendation R-05-16, previously classified "Open—Await Response," is reclassified "Open—Response Received."

The accidents in Macdonald and Graniteville clearly demonstrate that punctures of tank cars transporting chlorine and other poisonous liquefied gases can, within minutes, result in the release of fatal quantities of the toxic gases. The Safety Board recognized in the Graniteville investigation that certain poisonous liquefied gases that are poisonous by inhalation, if released, present such a severe danger to nearby citizens that operational measures, in addition to improving the structural integrity of tank cars, are needed to minimize the vulnerability of these tank cars in an accident. Accordingly, the Safety Board reiterates Safety Recommendation R-05-16 to the FRA.

Work Schedules and Limbo Time

The Safety Board recognizes that work as a train crewmember entails an unpredictable job schedule that can make it difficult for employees to effectively balance their personal and work lives. During those periods when the demand for crews exceeds the supply, the additional pressure on available crewmembers can make achieving such a balance particularly difficult. These conditions make it inevitable that even the most conscientious railroad employees will occasionally find themselves "caught short,"

without having received adequate rest before being called back to work. Although it cannot be known exactly what the engineer and conductor of the UP train would have done if they had known they would be called for the accident train shortly after midnight, it is clear that they were taking the chance that they would not be called to work when they were. In this case, the unpredictability of their work schedules led them to make what would prove to be imprudent use of their personal time. The Safety Board therefore concludes that the unpredictability of their work schedules may have encouraged the UP engineer and conductor to delay obtaining rest in the hope that they would not be called to work until later on the day of the accident.

The minimum rest periods prescribed by Federal regulations do not take into account either rotating work schedules or the accumulated hours spent working and in limbo time, both of which can affect the ability of an employee to obtain full rest and recuperation between job assignments. While limbo time is most often associated with a crew's travel time to their final release point after the expiration of their 12-hour service limit, the time spent awaiting transportation can be significant, as the Safety Board documented for the San Antonio Service Unit and the entire UP system during its investigation of the Macdona accident.

During an 8-week period in 1997, the UP had three collisions that resulted in five employee fatalities. The FRA responded by initiating a comprehensive systemwide safety review of the UP's operations seeking ways to correct systemic safety shortcomings. The FRA concluded that there was:

significant evidence of ineffective crew utilization, which leads directly to crew fatigue, stress, a lowering of morale, violations of the hours of service act and reduced ability to comply with operating rules. The end effect is train accidents and employee fatalities. *For example: crews being left on trains after the expiration of the Hours of Service. Sometimes in excess of two hours is spent awaiting arrival of crew vans or relief crews. Crews expire under the Hours of Service Act approximately 75 percent of the time. This severely adds to crew unavailability and compounds rest and fatigue issues.* [Emphasis added.]

The Safety Board acknowledges that the amount of limbo time incurred by crews on the UP system or the San Antonio Service Unit is neither causal nor contributory to the Macdona accident. Nevertheless, the Board is concerned that, because minimum rest periods prescribed under the hours-of-service regulations do not take limbo time into account, such time could have cumulative detrimental effects on crewmember fatigue. The Safety Board therefore concludes that limbo time, which is limited neither by Federal regulation nor railroad operating rules, could be a factor in crewmember fatigue in that required rest periods do not take into account the extended hours of wakefulness before the rest period begins. The combination of erratic work schedules and excess limbo time would be expected to have a detrimental impact on crewmember fatigue. The Safety Board therefore believes that the FRA should require railroads to use scientifically based principles when assigning work schedules for train crewmembers, which consider factors that impact sleep needs, to reduce the effects of fatigue. Further, the Safety Board believes that the FRA should establish requirements that limit train crewmember limbo time to address fatigue.

Positive Train Control

The Safety Board remains concerned about the safety of railroad operations where backup systems are not available to intervene when, as in this accident, a train crew operates a train improperly or fails to comply with wayside signals. Board accident investigations over the past three decades have shown that the most effective way to prevent train-to-train collisions is through the use of a positive train control (PTC) system that will automatically assume some control of a train when the train crew does not comply with signal indications.

Over the years, the Safety Board has issued a series of relevant recommendations, and PTC has remained on the Board's Most Wanted Transportation Safety Improvements list since 1990. The most recent safety recommendation relating to PTC, Safety Recommendation R-01-6, was issued to the FRA as a result of the Board's investigation of a fatal train collision in Bryan, Ohio.⁴⁸

R-01-6

Facilitate actions necessary for development and implementation of positive train control systems that include collision avoidance, and require implementation of positive train control systems on main line tracks, establishing priority requirements for high-risk corridors such as those where commuter and intercity passenger railroads operate.

Based on a March 27, 2002, letter in which the FRA outlined steps that it had taken toward "achieving the proper atmosphere in the rail industry to allow for the development and implementation of PTC," the Safety Board classified Safety Recommendation R-01-6 "Open—Acceptable Response."

In answer to an April 17, 2003, letter from the Safety Board asking for an update on actions regarding this safety recommendation, the FRA responded, in a May 5, 2003, letter, that it was "moving forward across a broad front to create the conditions under which PTC systems can be more widely deployed on the national rail system." In the letter, the FRA detailed some of the steps the agency was taking in the following areas:

- Providing a radio-navigation infrastructure and ensuring adequate spectrum
- Facilitating positive train control through regulatory change
- Supporting the demonstration and deployment of candidate technologies
- Analyzing costs and benefits

The FRA stated that the agency was "doing everything within its power to prepare the way for PTC and encourage its rapid deployment." In the wake of additional accidents

⁴⁸ National Transportation Safety Board, *Collision Involving Three Consolidated Rail Corporation Freight Trains Operating in Fog on a Double Main Track Near Bryan, Ohio, January 17, 1999*, Railroad Accident Report NTSB/RAR-01/01 (Washington, DC: NTSB, 2001).

that would have been prevented had PTC systems been installed, the Board reiterated Safety Recommendation R-01-6 in 2003 and again in 2005 after its investigations of railroad accidents in Placentia, California⁴⁹ and Chicago, Illinois.⁵⁰

The Safety Board hosted a seminar on PTC at the NTSB Academy in March 2005, and the Board is aware of several initiatives in the railroad industry to test PTC installations. On March 7, 2005, the FRA issued a performance standard for processor-based signal and train control systems, which became effective on June 6, 2005. In its May 16, 2006, response to the Board's most recent reiteration of Safety Recommendation R-01-6, the FRA noted these accomplishments and elaborated on the various pilot tests underway by Amtrak and the Class I railroads. While it is encouraging that the FRA has moved forward on performance standards and that other PTC pilot projects are underway, the Safety Board remains concerned that it has taken so long for the FRA to require, and for the railroad industry to develop and implement, such systems.

The Safety Board concludes that the Macdona, Texas, accident is another in a long series of railroad accidents that could have been prevented had there been a PTC system in place at the accident location.

Train Crew Protection From Inhalation Hazards

The Safety Board has found that freight train crews may survive collisions and derailments only to be injured or killed by hazardous materials released in the accident. In this accident, both UP crewmembers escaped serious injury in the collision only to become incapacitated or, in the case of the conductor, fatally injured as a result of the subsequent release of chlorine gas. If the UP crewmembers had been wearing appropriate, fully functioning emergency escape breathing apparatus when they walked away from the collision site, they might have been able to escape the chlorine vapors.

The consequences of this accident are similar to those of the previously referenced January 6, 2005, collision and derailment in Graniteville, South Carolina. A misaligned switch allowed a main line train to enter a siding and strike a standing train. As a result of the collision, a tank car on the striking train was punctured and released chlorine gas. The crew of the striking train survived the collision and exited the locomotive unassisted but could not escape exposure to the chlorine gas. The conductor and engineer were able to walk some distance from the collision where they were then transported to hospitals. The conductor was treated and released; the engineer died several hours later from inhalation of the toxic gas.

⁴⁹ National Transportation Safety Board, *Collision of Burlington Northern Santa Fe Freight Train With Metrolink Passenger Train, Placentia, California, April 23, 2002*, Railroad Accident Report NTSB/RAR-03/04 (Washington, DC: NTSB, 2003).

⁵⁰ National Transportation Safety Board, *Derailment of Northeast Illinois Regional Commuter Railroad Train 519 in Chicago, Illinois, October 12, 2003*, Railroad Accident Report NTSB/RAR-05/03 (Washington, DC: NTSB, 2005).

As a result of the Safety Board's investigation of the Graniteville collision and derailment, on December 12, 2005, the Board issued the following safety recommendation to the FRA:

R-05-17

Determine the most effective methods of providing emergency escape breathing apparatus for all crewmembers on freight trains carrying hazardous materials that would pose an inhalation hazard in the event of unintentional release, and then require railroads to provide these breathing apparatus to their crewmembers along with appropriate training.

In the advance copy of the FRA's June 30, 2006, letter, the FRA notes that in response to the recommendation it will begin a research effort this year to ascertain whether and in what way the recommendation can be accomplished. The Safety Board considers the failure of the FRA to respond to this safety recommendation in a timely manner to be unacceptable. However, because the FRA is initiating a research effort in response to this recommendation, Safety Recommendation R-05-17, previously classified "Open—Await Response," is reclassified "Open—Acceptable Response." Further, the Safety Board reiterates Safety Recommendation R-05-17 to the FRA.

Conclusions

Findings

1. On the day of the accident, the crew of the accident Union Pacific Railroad train failed to operate their train in accordance with operating rules and in compliance with wayside signal indications, to include failing to take any action in response to the *stop* signal at the west end of the Macdona siding.
2. The following were neither causal nor contributory to the accident: weather conditions, signal operation, equipment performance, track condition, drug use, or crew training and qualifications.
3. The Union Pacific Railroad engineer's combination of sleep debt, disrupted circadian processes, limited sleep through the weekend, and long duty tours in the days before the accident likely caused him to start the accident trip with a reduced capacity to resist involuntary sleep.
4. The Union Pacific Railroad conductor's lack of sufficient rest before reporting to work, the disruption to his previous work/rest pattern that resulted from his change in work schedule, and his alcohol consumption on the evening before the accident likely combined to reduce his capacity to remain awake and alert during the accident trip.
5. Neither the engineer nor the conductor of the Union Pacific Railroad train made effective use of the time that was available to them, between the time they were released from their previous assignments and the time they were called for the accident trip, to obtain rest.
6. The engineer of the Union Pacific Railroad train likely experienced one or more periods of microsleep early in the accident trip, and these were probably followed by a deeper descent into sleep as the train traveled past the signal at the east end of the Macdona siding.
7. The conductor of the Union Pacific Railroad train was most likely asleep during much of the accident trip.
8. Even though the initial dispatch of emergency response resources to the accident was timely, the overall execution of the incident command process during the response effort was not timely, effective, or appropriate.
9. The chlorine tank car that released a portion of its load in this accident was punctured during the derailment by impact with the left side frame member of the flatcar loaded with steel plates that was four cars ahead of the chlorine car in the train.

10. The shell of the punctured chlorine tank car in this accident would have been susceptible to catastrophic fracture if it had experienced a large penetration of several feet or more.
11. The unpredictability of their work schedules may have encouraged the Union Pacific Railroad engineer and conductor to delay obtaining rest in the hope that they would not be called to work until later on the day of the accident.
12. Limbo time, which is limited neither by Federal regulation nor railroad operating rules, could be a factor in crewmember fatigue in that required rest periods do not take into account the extended hours of wakefulness before the rest period begins.
13. The Macdona, Texas, accident is another in a long series of railroad accidents that could have been prevented had there been a positive train control system in place at the accident location.

Probable Cause

The National Transportation Safety Board determines that the probable cause of the June 28, 2004, collision of Union Pacific Railroad train MHOTU-23 with BNSF Railway Company train MEAP-TUL-126-D at Macdona, Texas, was Union Pacific Railroad train crew fatigue that resulted in the failure of the engineer and conductor to appropriately respond to wayside signals governing the movement of their train. Contributing to the crewmembers' fatigue was their failure to obtain sufficient restorative rest prior to reporting for duty because of their ineffective use of off-duty time and Union Pacific Railroad train crew scheduling practices, which inverted the crewmembers' work/rest periods. Contributing to the accident was the lack of a positive train control system in the accident location. Contributing to the severity of the accident was the puncture of a tank car and the subsequent release of poisonous liquefied chlorine gas.

Recommendations

As a result of its investigation of the June 28, 2004, collision and derailment in Macdona, Texas, the National Transportation Safety Board makes the following safety recommendations:

New Recommendations

To the Federal Railroad Administration:

1. Require railroads to use scientifically based principles when assigning work schedules for train crewmembers, which consider factors that impact sleep needs, to reduce the effects of fatigue. (R-06-14)
2. Establish requirements that limit train crewmember limbo time to address fatigue. (R-06-15)

To the Union Pacific Railroad:

3. Use the Macdona collision as a case study in fatigue awareness training to illustrate the shared responsibilities of the carrier to provide an employee the opportunity for adequate sleep and of the employee to acquire sleep sufficient to work at a safe level of alertness, and the options available if adequate sleep is not obtained. (R-06-16)

To the Brotherhood of Locomotive Engineers and Trainmen and the United Transportation Union:

4. Use this accident as a fatigue case study to illustrate the responsibility of the carrier to provide an employee the opportunity for adequate sleep and the responsibility of the employee to acquire sleep sufficient to work at a safe level of alertness, and the options available if adequate sleep is not obtained. Present this case study to your members at meetings, through written materials, and other appropriate methods. (R-06-17)

Recommendations Reiterated in This Report

To the Federal Railroad Administration:

R-04-4

Conduct a comprehensive analysis to determine the impact resistance of the steels in the shells of pressure tank cars constructed before 1989. At a minimum, the safety analysis should include the results of dynamic fracture toughness tests and/or the results of nondestructive testing techniques that provide information on material ductility and fracture toughness. The data should come from samples of steel from the tank shells from original manufacturing or from a statistically representative sampling of the shells of the pre-1989 pressure tank car fleet.

R-04-5

Based on the results of the Federal Railroad Administration's comprehensive analysis to determine the impact resistance of the steels in the shells of pressure tank cars constructed before 1989, as addressed in Safety Recommendation R-04-4, establish a program to rank those cars according to their risk of catastrophic fracture and separation and implement measures to eliminate or mitigate this risk. This ranking should take into consideration operating temperatures, pressures, and maximum train speeds.

R-04-6

Validate the predictive model the Federal Railroad Administration is developing to quantify the maximum dynamic forces acting on railroad tank cars under accident conditions.

R-04-7

Develop and implement tank car design-specific fracture toughness standards, such as a minimum average Charpy value, for steels and other materials of construction for pressure tank cars used for the transportation of U.S. Department of Transportation class 2 hazardous materials, including those in "low-temperature" service. The performance criteria must apply to the material orientation with the minimum impact resistance and take into account the entire range of operating temperatures of the tank car.

R-05-16

Require railroads to implement operating measures, such as positioning tank cars toward the rear of trains and reducing speeds through populated areas, to minimize impact forces from accidents and reduce the vulnerability of tank cars transporting chlorine, anhydrous ammonia, and other liquefied gases designated as poisonous by inhalation.

R-05-17

Determine the most effective methods of providing emergency escape breathing apparatus for all crewmembers on freight trains carrying hazardous materials that would pose an inhalation hazard in the event of unintentional release, and then require railroads to provide these breathing apparatus to their crewmembers along with appropriate training.

Recommendations Reclassified in This Report

To the Federal Railroad Administration:

R-04-4

Conduct a comprehensive analysis to determine the impact resistance of the steels in the shells of pressure tank cars constructed before 1989. At a minimum, the safety analysis should include the results of dynamic fracture toughness tests and/or the results of nondestructive testing techniques that provide information on material ductility and fracture toughness. The data should come from samples of steel from the tank shells from original manufacturing or from a statistically representative sampling of the shells of the pre-1989 pressure tank car fleet.

Safety Recommendation R-04-4, previously classified “Open—Unacceptable Response,” is reclassified “Open—Acceptable Response” in the “Previous Safety Board Actions Regarding Tank Cars” section of this report.

To the Federal Railroad Administration:

R-04-7

Develop and implement tank car design-specific fracture toughness standards, such as a minimum average Charpy value, for steels and other materials of construction for pressure tank cars used for the transportation of U.S. Department of Transportation class 2 hazardous materials, including those in “low-temperature” service. The performance criteria must apply to the material orientation with the minimum impact resistance and take into account the entire range of operating temperatures of the tank car.

Safety Recommendation R-04-7, previously classified “Open—Unacceptable Response,” is reclassified “Open—Acceptable Response” in the “Previous Safety Board Actions Regarding Tank Cars” section of this report.

To the Federal Railroad Administration:R-05-16

Require railroads to implement operating measures, such as positioning tank cars toward the rear of trains and reducing speeds through populated areas, to minimize impact forces from accidents and reduce the vulnerability of tank cars transporting chlorine, anhydrous ammonia, and other liquefied gases designated as poisonous by inhalation.

Safety Recommendation R-05-16, previously classified “Open—Await Response,” is reclassified “Open—Response Received” in the “Previous Safety Board Actions Regarding Tank Cars” section of this report.

To the Federal Railroad Administration:R-05-17

Determine the most effective methods of providing emergency escape breathing apparatus for all crewmembers on freight trains carrying hazardous materials that would pose an inhalation hazard in the event of unintentional release, and then require railroads to provide these breathing apparatus to their crewmembers along with appropriate training.

Safety Recommendation R-05-17, previously classified “Open—Await Response,” is reclassified “Open—Acceptable Response” in the “Train Crew Protection From Inhalation Hazards” section of this report.

BY THE NATIONAL TRANSPORTATION SAFETY BOARD

Mark V. Rosenker
Acting Chairman

Deborah A. P. Hersman
Member

Kathryn O’Leary Higgins
Member

Adopted: July 6, 2006

Appendix A

Investigation

The National Response Center notified the National Transportation Safety Board of the Macdona accident on June 28, 2004, at 7:22 a.m, eastern daylight time. The investigator-in-charge and other members of the Safety Board investigative team were launched from the Washington, D.C., Headquarters office and from the Los Angeles, California, field office. Investigative groups were established to study operations, track, signals, mechanical, survival factors, human performance, and hazardous materials issues. No Safety Board Member went to the accident site.

The Union Pacific Railroad, the Federal Railroad Administration, the BNSF Railway Company, the Texas Railroad Commission, the Brotherhood of Locomotive Engineers and Trainmen, the United Transportation Union, the city of San Antonio, Texas, and Bexar County, Texas, assisted the Safety Board in its investigation.

As part of its investigation of the Macdona accident, the Safety Board held a public hearing at its Headquarters in Washington, D.C., on April 26 and 27, 2005. Parties to the hearing included the Federal Railroad Administration, the Union Pacific Railroad, the BNSF Railway Company, the Brotherhood of Locomotive Engineers and Trainmen, and the United Transportation Union. Observers at the hearing were the city of San Antonio, Texas, and Bexar County, Texas.

